Cognitive Control in Auditory Processing

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Dissertation for the degree philosophiae doctor (PhD)

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Contents

Abstract

The dichotic listening experimental paradigm creates an ambiguous situation for the participant by presenting two auditory stimuli simultaneously, one in each ear. Which of the stimuli the participant reports has previously been shown to depend on language lateralization and attention instructions. The current work presents three studies that introduce a novel way of manipulating which stimulus is reported in dichotic listening. The first report showed that priming one of the stimuli in the dichotic situation biases response selection away from the primed dichotic stimulus, and that the manipulation is effective with both auditory and visual priming. The second report showed that the priming manipulation can be combined with the more traditional attention instructions manipulation, and that the two types of experimental manipulation showed an interaction. The third report used fMRI to show that the task evokes activation in posterior medial frontal and right ventrolateral brain areas, and presented a theoretical model in which the activations reflect detection of cognitive conflict and inhibition, respectively. The present thesis thus shows that priming in the dichotic listening experimental paradigm modulates cognitive mechanisms, which has effects on response selection. The experimental task may prove useful as an easily administered test of inhibition in the auditory domain, with implications for examining attention functions in healthy and clinical groups.

Acknowledgements

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1. Attention

1.1 Historical background of attention research

Early research following James (1890) tried to determine to what extent attention is a unified or distributed cognitive resource (Driver, 2001). It was acknowledged that the attentional process starts out with a broad perceptual focus, in the sense that a wide array of stimuli are available for further processing, and that later selections are made in order to focus processing towards some aspects of the stimulus situation and away from other aspects of the stimulus situation (selective attention). Cherry (1953) and Broadbent (1954) introduced the dichotic listening experiment for studying attention. In dichotic listening experiments there are two sources of information (separate auditory input in each ear), and the factors influencing which signal is attended are examined. Some models were proposed where the selection of information for further processing is done relatively early in the information processing chain, and the subsequent processing is largely serial (early selection models, Broadbent, 1958; Treisman, 1969), while other models assumed that the selection happens at a later stage, and parallel processing of the incoming stimuli is performed to a larger extent (late selection models, Deutsch & Deutsch, 1963; Duncan, 1980).

1.2 Bottom-up and top-down cognitive processes

Perception and attention are information processes that act on incoming signals, while at the same time interacting with higher cognitive processes. The individual on the one hand needs to gather information from its surroundings, while on the other hand needs to direct the perceptual process and to sort the input into categories. Attention can automatically be attracted by salient features in the environment, such as a strong contrast between stimuli or a sudden occurrence of a stimulus, but attention can also be directed through factors such as intentions, previous experience or predictability of the stimulus material. In information processing terms, attention thus needs to be explained as influencing perception both “from the bottom and up” and “from the top and down”.

1.2.1 Bottom-up processing

Bottom-up processing is typically described as input-driven, linear and according to a feed-forward principle. Bottom-up processes are initiated at a low level in the cognitive hierarchy and influence the information processing at higher levels (Graboi & Lisman, 2003). Feature detectors, single neurons that function as encapsulated information processing units that respond to specific features in the environment are typical examples of bottom-up processing in perception. Visual feature detectors in V1 show increased activation measured with single cell recordings when presented with visual stimuli with a particular spatial orientation (Hubel & Wiesel, 1968), and an auditory analogue was shown by Rees and Möller (1983). Bottom-up processing in perception is done by simple stimulus features being recognized at one level of processing and combined into more complex stimulus arrays on the next processing level, and finally ending up as a unified percept. Yantis and Jonides (1984; 1990) demonstrated how bottom-up processes can control attention by showing how attention can be drawn to abruptly occurring stimuli. Studies have thus shown how bottom-up processes are involved in the perceptual and attentional process that allows us to understand the physical world. In a more general sense, the term “bottom-up” is used for any process that is initiated by exogenous stimulus input, and influences information processing on higher cognitive levels by using only feed-forward mechanisms.

1.2.2 Top-down processing

The term top-down is used to describe how cognitive processes are influenced by intention, experience and conscious thought. Such processes involve information processes on higher cognitive levels influencing the information processing performed on lower levels. Top-down processes are selective with regards to which of the available information is processed further, and the processing is non-linear, in the sense that information not only feeds upward through the system (from simple to more complex levels of processing), but there is also information flow from higher to lower processing levels (Corbetta & Shulman, 2002; Graboi & Lisman, 2003). A classical example of top-down influences can be seen in the way context influences perception (Selfridge, 1955); the same visual input can be interpreted as different letters depending on the surrounding letters, and thus an ambiguous letter can be read as either the H in THE or the A in CAT. In this case, information on the word processing level influences information processing on the letter processing level. From this example, an important aspect in the understanding of top-down processes is emphasized: Top-down does not necessarily imply that the process is self generated, as would be the case with intentional control of attention, but can also be initiated by external events. The participant does not intent to read the ambiguous letter as H or A, it is the (bottom-up) perception of the surrounding letters that automatically initiates a top-down effect on the perception of the ambiguous letter. A further example is the classical Posner task (Posner, 1980), which showed that an external cue could modulate attention in two different ways. One type of modulation is initiated by a lateralized cue, and is proposed to be happen through a bottom-up attention mechanism, while the other type is initiated by a central symbol signalling one of the directions, and is proposed to be caused by a top-down attention mechanism. This shows that top-down attention modulation can be initiated on the stimulus level as well as initiated by higher level constructs. The defining feature of a the top-down process is that some processing on a cognitive higher level (for the Posner task: the interpretation of what a centralized cue represents, based on prior experience with the cue) has an influence on a lower cognitive level (for the Posner task: the perceptual sensitivity to the left or right side of the visual field).

Studies have shown how instructions to attend specific stimulus features can modulate neural activity in primary perceptual areas like the visual cortices (O'Craven, Rosen, Kwong, Treisman, & Savoy, 1997), or the activity in perceptual areas specific for processing particular types of features, such as faces or places (Gazzaley, Cooney, McEvoy, Knight, & D'Esposito, 2005). This shows how feedback from higher level attention network located in the frontal cortex can influence lower level processing in occipital and temporal areas (for reviews, see Chun & Marois, 2002; Kastner & Ungerleider, 2000). Single cell recordings have shown (Hasegawa, Peterson, & Goldberg, 2004) that some cells signal whether a learned association is valid for a specific context, thus showing how learning is modulated by top-down mechanisms. These studies show that cognitive processes not only consist of linear accumulation of exogenous inputs, but that higher level concepts, such as intention, expectation and perceptual categories influence lower level processing.

1.2.3 Integration of bottom-up and top-down processes

Cognitive systems are seldom sufficiently explained by bottom-up or top-down processes alone. It could be argued that complex processes such as perception cannot be accounted for by using only one type of processing: bottom-up visual input cannot end up in perceptual categories without these categories being pre-existing and thus having non-linear influences on processing, while on the other hand, top-down mechanisms of perception need input from lower levels for the categorization. It thus becomes apparent that an integration of the two types of processes is necessary for a system to function. In line with this, when the two types of processes are contrasted in current models and theories in cognitive psychology, it is usually done in order to discuss the balance between bottom-up and top-down influences for a given situation. Sperry (1988, pp 609) described modern cognitive psychology thus: "Control from below upward is retained but is claimed to not furnish the whole story. The full explanation requires that one take into account new, previously nonexistent, emergent properties, including the mental, that interact causally at their own higher level and also exert causal control from above downward." Thus, rather than discussing whether perception or attention are top-down or bottom-up processes, one may discuss whether a specific empirical finding is the result of bottom-up or top-down influences. As an example, if one observes a decline in responsiveness to repeated exposures of a stimulus, one may attempt to explain it as either as a bottom-up process, such as habituation (Thompson & Spencer, 1966), or as a top-down process, such as negative priming (Tipper, 1985). Yantis and Jonides (1990) demonstrated that the focus of visual attention balance between being controlled by bottom-up and top-down processes, and how it can be manipulated by subtle experimental manipulations.

1.3 The cognitive control view of attention

Current work in cognitive neuroscience (e.g. Cabeza & Nyberg, 2000; Corbetta & Shulman, 2002; Posner, 2004) has shown that attention should not be viewed as a general ability to focus cognitive resources. Posner’s work (for a review, see Posner & Petersen, 1990) has suggested an attentional system that can be separated into three major functions: orienting to sensory events, detecting signals for focal processing and maintaining a vigilant state. By this approach it becomes apparent that in research one should not approach attention as a unitary concept, but rather study the sub-components separately. Cohen and colleagues (Cohen, Aston-Jones, & Gilzenrat, 2004, pp 71) stated that “If attention is such a varied phenomenon, how can we make progress in understanding it? There are two simple answers to this question: Be precise about the specific (aspects of the) phenomena to be studied, and be precise about the mechanisms thought to explain them.”

1.3.1 Cognitive control

The broad and unspecific concept “attention” needs to be divided into separate functions, each of which needs to be carefully defined by theoretical terms and by the experimental paradigms that are used to study them (Cohen, Aston-Jones, & Gilzenrat, 2004). One aspect of attention that has been extracted and that has been the subject of a rapidly increasing number of publications is the concept of ”cognitive control“. The term cognitive control has been used to describe the mental processes that allow us to guide thought and behaviour in accordance with our goals (Aron, 2007; Braver & Barch, 2006; Egner & Hirsch, 2005a; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004). When there are several alternative ways to process information, cognitive control comes into play to specify which information should be processed and which should not, given the current context. In this sense, there is an overlap between the concept of cognitive control and what was discussed above as top-down influences on processing. The concept of cognitive control is also associated and partially overlapping with the concepts of executive function, supervisory attention system, controlled information processes, selective attention and decision making.

In the Stroop task (Stroop, 1935), where the names of colours are written in different coloured ink, the task in one condition is to process the colour information in order to report the colour of the ink, while the task in another condition is to process verbal information in order to read the words. The role of cognitive control is thus to influence the processing in the direction of different stimulus features depending on the context. In a real-life example, looking left before crossing the road is a good idea in most contexts, and then the information relevant to that response should be processed, but when visiting countries with left lane traffic it is better to look right, and cognitive control should ensure that information relevant to that response is processed in this context.

The term cognitive control was first introduced by Posner (Posner & Snyder, 1975), within the theoretical framework provided by Broadbent (1957; 1958). Several authors (Cohen & Servan-Schreiber, 1992; Grafman, 1994; Miller, 1999; Passingham, 1993) have proposed that cognitive control is localized to the prefrontal cortex (PFC). In an influential article, Miller and Cohen (2001) presented a neural network model for cognitive control of attention (the guided activation model) by expanding the "biased competition" framework that Desimone and Duncan (1995) developed to account for selective visual attention. According to the model, competition between neural populations is a fundamental principle of the PFC, and neural populations representing the potential stimulus features and responses share mutual inhibitory interconnections. The PFC maintains patterns of activation representing processing goals and the means to achieve them. Cognitive control is performed through top-down excitatory signals from task-demand units in the PFC, that biases the competition of lower level neural populations towards processing certain stimuli or responses. Cognitive control thus works through downstream sensitivity changes, and it can have effects on the processing of input, output, memory and emotion. Without PFC cognitive control, selection would always favour the most dominant stimulus or response, or the selection would be haphazard, which does appear to match clinical data (Miller & Cohen, 2001). A more detailed description of the neural machinery involved in the guided activation model follows below.

1.3.2 The guided activation model of cognitive control

The guided activation model of cognitive control (Miller & Cohen, 2001) was developed within the terminology of neural network models of cognitive systems (McClelland & Rumelhart, 1981). Such models consist of sets of mutually competitive information processing units, and the assumption is that these units on some level represent the signal processing performed by the neurons of the brain. Within a set of units, the processing unit that reaches the highest level of activation is the unit whose signal is processed further, meaning that the information represented by the unit becomes the perceived stimulus, the recalled memory trace, the selected response and so on, depending on where in the cognitive system the set is localised. The units are competitive in the sense that the activation of one unit decreases the activation of the alternative units in the set. The reactivity function of information processing units is non-linear in such a way that when a unit's levels of activation is low the unit has an inhibitory effect on the transmission of a signal, while when it has a high level of activation it has an excitatory effect on the transmission. Thus information inhibition can be modelled in a system restricted to having only excitatory connections.

The guided activation model of cognitive control (Miller & Cohen, 2001) proposed that some sets of units handle the processing of incoming information, one set of units maintains the current goals of the processing and influences the processing to fit the goals (the cognitive control set), while another set of units detects conflicts in the processing (the cognitive conflict set). An increase of activation of the conflict set has the effect of increasing the activation of the control set, and the level of conflict thus modulates the extent to which the goals influence the processing. An application of this type of model for cognitive control was shown in a neural network model for information processing in the Stroop task, presented by Cohen and colleagues (Cohen, Dunbar, & McClelland, 1990). The model postulated five sets of units, two sets of units representing each type of input (one for the orthographic information, one for the colour information), one set of output units representing the response alternatives, and two sets of units representing processing pathways between input and output, one for word reading and one for colour naming. Figure 1a shows an overview of a limited version of the model, shown with connections to the four potential inputs relevant for this part of the network. The pathway for word reading is initially stronger than the pathway for colour naming, due to overlearning of this type of response. This implies that given no task instruction, the pathway for word reading is the one most easily activated (shown in Figure 1b), making this response the "default" answer. Cognitive control is represented by adding a task-demand set (with units representing each of the types of task instruction), which modulates the relationship between stimulus and responses (see Figure 1c). These units can modulate the activation of the relevant processing pathways, making the lower level units more sensitive for task-relevant input. When cognitive control modulates the level of activation of the units, the throughput of information is suppressed or facilitated. In the model of the Stroop task, input is processed differently depending on which of the task-demand units in the cognitive control set is currently active (representing different task instructions), which in turn activates the different nodes in the pathway between stimulus and response. Within the model, the amount of activation of the cognitive control set is determined by the amount of activation of a cognitive conflict set. The cognitive conflict set is activated when there is co-activation of several units within a set. In Figure 1c this is shown as conflict between the two response alternatives, although the conflict can also occur on other levels.

Figure 1.

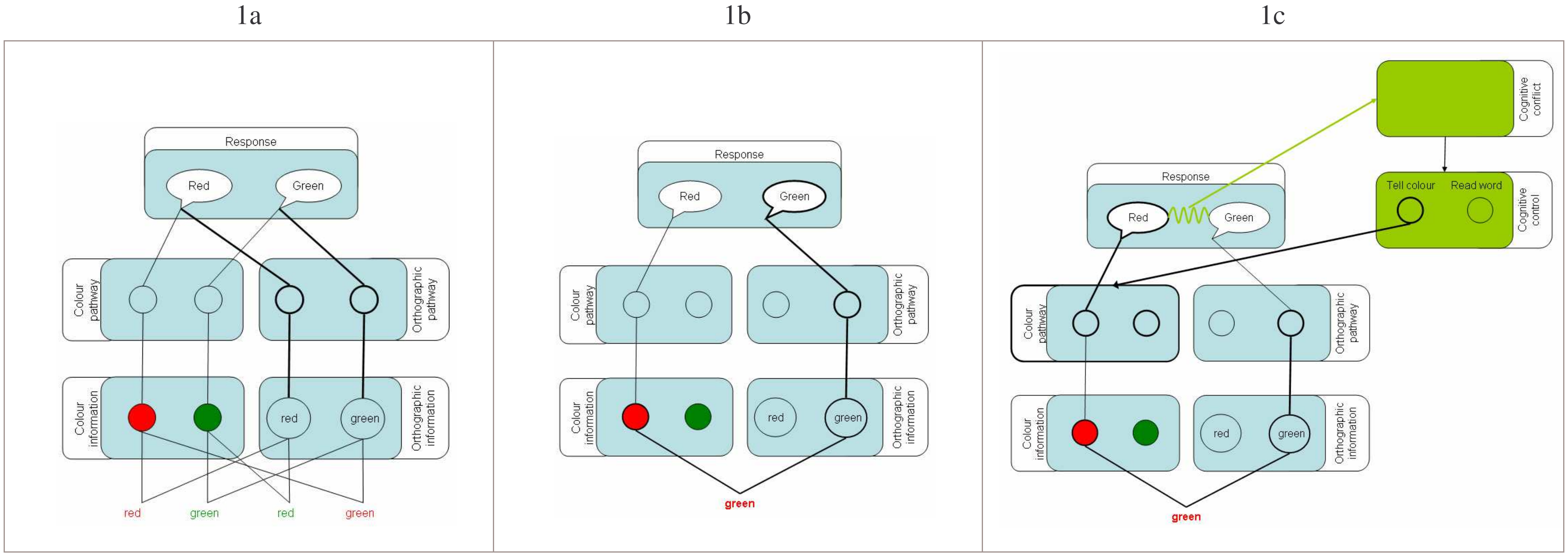

Figure 1: The figure, adapted from Miller & Cohen (2001) shows how a neural network model can implement cognitive control and account for the behavioural effects observed in the Stroop task. Figure 1a shows the network and the connections to the potential stimulus inputs the network can receive. The thicker nodes and lines for the orthographic pathway represents that overlearning has made this pathway the preponderant response. Figure 1b shows the network when given incongruent input. Although units in both pathways are activated, the preponderant salience of the orthographical pathway makes the orthographical information more dominant, thus determining the response. Figure 1c shows the addition of cognitive conflict and cognitive control sets. When instructions are to report colour, the cognitive control set may increase the activation of the colour pathway, and thus give the colour information more "weight" in the processing (the increase in activation is relative, the selection can also be done by suppressing the activation of the opposite pathway). Co-activation of several response alternatives is detected by a cognitive conflict set, which in turn enhances activation of the cognitive control set.

1.3.3 Cognitive conflict

Cognitive control is a general function of a cognitive system rather than a specific mechanism. How can such a term be operationalised, and which experimental designs can be used to study it? As mentioned above (section 1.3.1), cognitive control is assumed to be activated by conflicting information. In the guided activation theory described above (Miller & Cohen, 2001), this is operationalised as simultaneous activation of more than one unit within a set. On a more conceptual level, cognitive conflict may be defined as the co-existence of mutually exclusive states of information or information processes. From an information processing perspective, cognitive conflict is adverse as it increases the risk of crosstalk interference between alternative processing options (Mozer & Sitton, 1998). The information being in conflict may refer to stimulus representations, processing pathways or response options, and may be generated from external stimuli or from internal representations. Two simultaneous stimulus presentations may thus present a cognitive conflict if the context only allows for one stimulus to be perceived. There could also be conflict if an external stimulus is different from an internally generated expectation of what the stimulus will be. One may also experience cognitive conflict when two or more response programs are activated, but only one response can be committed.

According to Botvinick and colleagues (Botvinick, Braver, Barch, Carter, & Cohen, 2001), three different categories of experimental paradigms can be used to study cognitive conflict: Cognitive conflict will arise when an experiment has established some responses to be more accessible than others, but a different, non-dominant response is the correct response according to the task instructions. An example of this would be the Stroop task (Stroop, 1935), where word-reading is the pre-dominant response, but has to be overruled to perform the colour-naming task. A different example is the go/no-go task (Casey, 1997), in which the context establishes the “go” response to be the most frequent response, thus making it more difficult to perform the “no-go” response. In such situations there is a cognitive conflict between the preponderant response and the response indicated by the task instruction. A second type of situation in which cognitive conflict is studied, is in the case of underdetermined responses, i.e. when the situation demands a response, but several responses are equally correct. Examples of such tasks are when the participant is asked to generate a verb upon the presentation of a noun (Petersen & Petersen, 1988), or the letter fluency task (Spreen & Benton, 1969) where the participant is asked to generate nouns beginning with a certain letter that belong to a certain category. In such situations, there is a conflict between the various response alternatives that all have similar probabilities of being processed. A third type of task in which cognitive conflict is studied is when the participant is given a cognitively demanding task, and the trials on which the participant makes a mistake are examined. The assumption is that on these trials there is a conflict between the representation of what the correct response should have been, and the representation of the actual response made. Examples of such tasks are the flanker task (Eriksen & Eriksen, 1974) or a go/no-go task (Casey, 1997).

1.3.4 Functional localisation of cognitive control

Neuroimaging studies have localised cognitive control to the PFC (Cohen & Servan-Schreiber, 1992; Grafman, 1994; Miller, 1999; Passingham, 1993), and clinical work has shown that damage to frontal cortex causes problems with learning, adjusting behaviour, assessing behaviour, goal direction, all of which are tasks that are associated with cognitive control (e.g. Gehring & Knight, 2000; J. N. Wood & Grafman, 2003). Recent research has indicated that discernible structures within the frontal cortex perform various tasks related to cognitive control (Braver & Barch, 2006; Egner & Hirsch, 2005a; Miller & Cohen, 2001; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004).

A critical feature of the guided activation model of cognitive control (Miller & Cohen, 2001) is that detection of cognitive conflict in the system modulates the extent of cognitive control. Although the initial statement of the model postulated two different mechanisms, it did not emphasize the distinction between the two functions into specific neuroanatomical correlates in the PFC. Previous electrophysiological studies on phenomena such as error-related negativity (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990; Gehring & Willoughby, 2002) and feedback error related negativity (Holroyd, Dien, & Coles, 1998) have indicated medial frontal sources, and this research can to some extent be integrated into the framework of conflict detection (see Botvinick et al., 2004). A review paper by Ridderinkhof, Ullsperger, Crone and Nieuwenhuis (2004) examined previous neuroimaging and electrophysiological research on the human and primate brain, and found that tasks that involve pre-response conflict, decision uncertainty, response error and negative feedback, all which are assumed to increase cognitive conflict, were found to activate dorsal anterior cingulate cortex and more dorsal PFC areas, including the pre-supplementary motor area. This area was labelled the posterior medial frontal cortex (pMFC) by the authors. Botvinick and colleagues (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999) building on work by Gratton (Gratton, Coles, & Donchin, 1992) argued that in a flanker task (Eriksen & Eriksen, 1974) incompatible trials that followed compatible trials would cause an increase in cognitive conflict. In a functional magnetic resonance imaging (fMRI) study they showed that pMFC activation increased for low-control/high-conflict trials, which were assumed to increase conflict more than control, compared to high-control/low-conflict trials, which were assumed to increase control more than conflict. There is today consensus that medial frontal cortical areas are involved in monitoring and detecting cognitive conflict (Gehring & Knight, 2000; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004), although there is some disagreement regarding the exact position within the medial frontal cortex (see Braver & Barch, 2006). It is possible that various experimental tasks invoking different types of conflict return different neuroanatomical correlates. As an example, Ridderinkhof and colleagues (Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004) showed that pre-response conflict was typically reported more dorsally than error processing. A recurring question is at which level of the cognitive system the conflict arises. Response conflict is discussed most often in the literature, but Miller and Cohen’s model (2001) also allows for conflict on other levels. Recent studies (van Veen & Carter, 2005;

West, Jakubek, Wymbs, Perry, & Moore, 2005) indicate that different sources of conflict may be neuroanatomically dissociated.

Ridderinkhof and colleagues (Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004) suggested that the detection of conflict in pMFC signals the need for cognitive control, while lateral and orbitofrontal PFC are involved in adjusting task performance to reduce conflict. A similar model has been proposed by Botvinick and colleagues (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004), who argued that the guided activation model of cognitive control (see section 1.3.2) postulate anatomically separable mechanisms; while pMFC appears to detect cognitive conflict (i.e. conflict monitoring), lateral frontal cortex, and in particular dorsolateral prefrontal cortex (DLPFC) employs strategies to resolve the conflict (i.e. cognitive control). Using an fMRI study with a Stroop task-switching paradigm, MacDonald and colleagues (2000) argued that activation in medial frontal cortex and DLPFC could be dissociated by showing that changing the task instructions, which increases cognitive control demands, had an effect on DLPFC activation, while changing stimulus congruency, which increases cognitive conflict, had an effect on medial frontal activation. A recent paper by Dosenbach and colleagues (Dosenbach et al., 2006) found that pMFC and ventrolateral PFC was consistently activated across task switching. The neuroanatomical locations found in this study are thus somewhat deviating from the typical findings, and the authors interpret the pMFC activation to represent control implementation, not only conflict monitoring. See Braver and Barch (2006) for a discussion of the validity of these conclusions. All in all, there appears to be consensus for a theoretical and neuroanatomical division in which the pMFC is seen as important for registering cognitive conflict, while the DLPFC is seen as important for employing strategies to resolve the cognitive conflict according to context and task demands. See Figure 2 for an illustration of where in the brain cognitive conflict detection (2a) and cognitive control (2b) are assumed to be instantiated.

Figure 2:

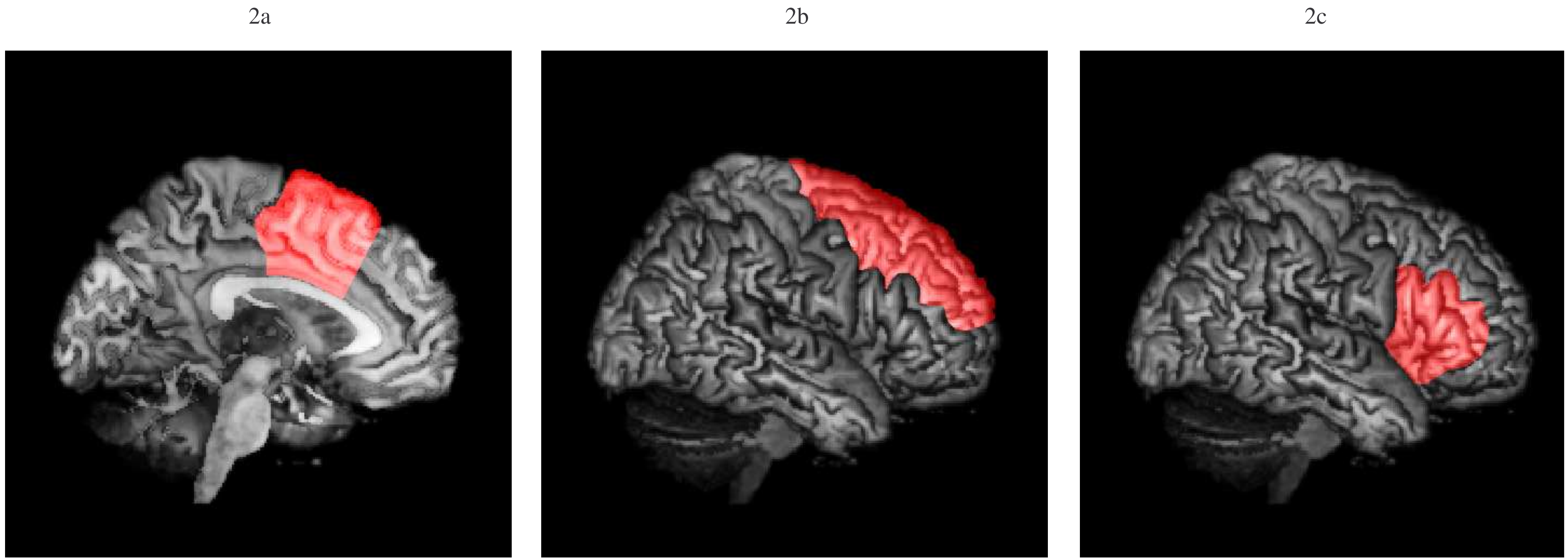

Figure 2: The figure illustrates the areas of posterior medial frontal cortex (2a), dorsolateral prefrontal cortex, defined as superior and middle frontal gyrus (2b) and right inferior frontal gyrus (IFG) on the ventrolateral frontal cortex (2c). These areas are believed to be involved in detecting cognitive conflict, context sensitivity, and inhibition, respectively.

As mentioned earlier (see section 1.3.1), neural network models view cognitive systems as sets of mutually competitive units. Form this perspective, cognitive conflict can be seen as simultaneous activation of more than one unit on the same set, and cognitive control can be seen as the process of adjusting the unit activations in order to reach a stable state where one unit wins the competition. Logically, the adjustments in order to reduce the cognitive conflict of a system can be done through two different approaches: By amplifying one pathway, thus facilitating the processing of that information (see section 1.3.5), or by inhibiting the competing input, thus facilitating the processing of opposing information (see section 1.3.6), or a combination of the two approaches. A similar argument has been made by Aron (2007).

1.3.5 Conflict resolution by facilitation

The function of cognitive control can be said to be to modulate the processing of information in order for the processing to fit with the current context information. One way of doing this is to bias the cognitive system in the direction of processing a certain sensory input or a response option through facilitation of the processing of task-relevant information. Such facilitation can be seen as synonymous with the focusing of attention. The facilitation effect brought into play by attentional focus resolves the cognitive conflict by allowing the task-relevant information to become more salient and thus to win the competition over the task-irrelevant information.

Electrophysiological studies have shown that event-related potentials (ERPs) are larger in the primary visual areas of one hemisphere when the participant is instructed to attend to the contralateral side (Heinze et al., 1994). This is taken to indicate that focusing of attention has the effect of lowering the firing threshold of neural populations representing the locations indicated by the instructions. This has later been supported by fMRI studies (e.g. Kanwisher, McDermott, & Chun, 1997; Liu, Slotnick, Serences, & Yantis, 2003), which have shown that the presentation of a stimulus can increase activation for different perceptual areas depending on which physical features (such as colour, motion or faces) participants are instructed to attend to. In addition to such studies that indicate facilitating effects of instructed attention on primary perceptual areas, other research has shown that PFC areas are sensitive for the conjunction of stimulus and context. An example of this is single-cell recordings in cue-learning paradigms in macaque monkeys (Hasegawa, Peterson, & Goldberg, 2004), where a cue causes PFC neurons to increase their firing rate, but only under the contextual circumstances in which this cue previously has signalled reward. This also ties into the previously mentioned statement (see 1.3.4) that context sensitivity (cognitive control) is represented in DLPFC.

1.3.6 Conflict resolution by inhibition

As an alternative to amplifying task-relevant information, cognitive conflict can also be resolved through inhibition of information that is not relevant for the given context or intentions. By suppressing task-irrelevant information, the task-relevant information gets a relative processing advantage. Several authors have argued that top-down inhibition is an important way in which responses (Aron & Poldrack, 2006), memory (Anderson & Green, 2001), emotion (Ochsner & Gross, 2005) and selective attention (Tipper, 1985) are controlled. Inhibition is in the current context understood as the active suppression of one state of information in order to resolve cognitive conflict. In contrast to bottom-up mechanisms that can have the overt effect of reducing responses, such as habituation, inhibition is considered to be a top-down mechanism, instantiated through processes initiated on a higher cognitive level. Further, inhibition is considered to be an active process, as opposed to a passive change of firing thresholds (Aron, 2007). It has been argued that inhibition is a poorly defined and overused concept, which is applied to processes working on diverse physiological, behavioural and psychological levels (MacLeod, Dodd, Sheard, Wilson, & Bib, 2003). Aron (2007) agreed to these caveats, and argued that inhibition needs to be studied in a clearly delineated domain, where the neuroanatomical areas involved and the functional relationships between them are already known. Using this approach, Aron's own research (Aron, Behrens, Smith, Frank, & Poldrack, 2007; Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003;

Aron & Poldrack, 2006; Aron, Robbins, & Poldrack, 2004) on motor response inhibition has indicated a network of cortical and subcortical structures to be involved in inhibition. However, Aron (2007) argued that the inhibitory system that has been identified through these investigations appears to also be involved in inhibition in other domains, pointing to the existence of a general inhibitory system.

As mentioned previously (see section 1.3.2), the guided activation model of cognitive control can accommodate information inhibition through the non-linear reactivity function. Inhibition on the behavioural level does not necessarily imply inhibition on the neural or computational level. In fact, whether inhibition or facilitation is done on a computational level may only be a question of framing. According to the biased competition model of Desimone and Duncan (1995), selective attention and inhibition are two sides of the same coin, as biasing in favour of the task-relevant or inhibiting the task-irrelevant could have the same effect on a functional level.

Several neuroimaging studies have found activation in right inferior frontal gyrus (IFG) in the ventrolateral PFC to correlate with tasks that require inhibition (Aron, 2007; Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Aron & Poldrack, 2006; Aron, Robbins, & Poldrack, 2004; Rubia, Smith, Brammer, & Taylor, 2003). Lesion studies have further supported right IFG as being involved in performing inhibitory processes (Aron, Monsell, Sahakian, & Robbins, 2004; Clark et al., 2007). Other studies have shown that patients with right PFC damage have reduced or reversed capacity for negative priming (Metzler & Parkin, 2000; Stuss et al., 1999), which could be caused by a loss of inhibitory function (see section 2.2). Chambers and colleagues (2006) showed that when the neural processing of right IFG was perturbed by applying transcranial magnetic stimulation (TMS) to that area, participants failed to inhibit responses that had been commenced. This finding added to the argument by showing that rather than merely co-correlating with inhibition, the neural population in right IFG is causally responsible for at least some inhibitory processes. See Figure 2c for location of right IFG.

2. Priming

Priming is “a change in the ability to identify or produce an item as a result of a previous encounter with the item” (Schacter & Buckner, 1998b, pp 185). Priming is when a stimulus (the prime) is assumed to have an effect on how a stimulus presented later (the probe or target) is processed. Priming can be excitatory, in the sense that it facilitates subsequent processing of the same or a related stimulus (hereafter referred to as positive priming), or it can be inhibitory, in the sense that it impairs subsequent processing of the same stimulus (hereafter referred to as negative priming). Small variations in experimental design within the same experiment can determine whether positive or negative priming effects are produced. The processes elicited by priming are assumed to be automatic and independent of intention, and effects of priming can be seen in the absence of awareness of the prime (Cheesman & Merikle, 1984; Dehaene et al., 1998).

2.1 Positive priming

The term priming is often used synonymously with positive priming, i.e. the facilitation of processing of a stimulus or stimulus feature due to having previously been presented with the same or a related stimulus (Schacter & Badgaiyan, 2001). An everyday example of positive priming is the way in which a familiar name is immediately recognized when scanning a page of text, or a familiar face is immediately recognized in a crowd of faces. Positive priming can also be seen on the conceptual level, in the sense that a prime from one semantic category may cause a subsequent word-stem to be completed as a word belonging to the same semantic category (Schacter, Badgaiyan, & Alpert, 1999). Positive priming is often explained in terms of a bottom-up “spreading activation” mechanism in a neural network model, which proposes that processing a stimulus implies activation of the neural population associated with that stimulus, which has a residual effect of lowering the threshold for subsequent reactivation for that part of the network for a given time. This has the overt effect of facilitating recognition and responding when the same stimulus, or a stimulus belonging to the same semantic category is repeated. Schacter and Buckner (1998b) and Henson (2003) point to similarities between priming and the concept of repetition suppression in animal models, where repeated exposure to a stimulus reduces overt behaviour and the responsiveness of cells in inferior temporal cortex (see also Desimone, Miller, Chelazzi, & Lueschow, 1995). Neuroimaging studies of positive priming typically find reduced activation of various areas of the brain, in particular posterior cortical regions (Buckner et al., 1998; Schacter & Badgaiyan, 2001; Schacter & Buckner, 1998a). Positive priming on a conceptual level typically finds a reduction of activation in left PFC (Blaxton et al., 1996; Demb et al., 1995; Henson, 2003; Raichle et al., 1994), in the same brain areas that typically show increased activation for semantic encoding tasks. This could indicate that positive priming is related to memory functions, but rather than causing stimuli to be encoded, it causes stimuli to have less of an impact in terms of neural processing.

2.2 Negative priming

Repeating the presentation of a stimulus can under some circumstances result in impeding the processing of the stimulus, observable as a reduced ability to identify a stimulus or to produce a response, a phenomenon called negative priming (May, Kane, & Hasher, 1995; Tipper, 1985). In a typical negative priming experiment, stimuli are presented in sequential pairs, where experimental manipulations are made in order for one of the stimuli in the pair to be attended (S^a) while the other stimulus is unattended (S^u). The accuracy is lower and the response time (RT) is prolonged if the current S^a matches the S^u on the previous stimulus pair. An experiment that produces negative priming could be presented thus: On $trial^n$, two stimuli are presented at the same time, one instructed to be the S^a and one instructed to be the S^u. If S^a on $trial^{n+1}$ matches S^a on $trial^n$, the responses on $trial^{n+1}$ are faster and more accurate, and positive priming can be said to have occurred. On the other hand, if S^a on $trial^{n+1}$ matches S^u on $trial^n$, the responses are slower and less accurate, and negative priming can be said to have occurred.

The prevailing explanation of negative priming is through attention inhibition mechanisms (Houghton & Tipper, 1996; May, Kane, & Hasher, 1995; Tipper, 1985, 2001); On the presentation of a stimulus pair, the unattended stimulus (S^u) is inhibited in order to prevent it from interfering with the processing of the attended stimulus (S^a). When the attended stimulus (S^a) on the current trial matches the stimulus that was inhibited on the previous trial (the previous S^u), processing of the stimulus is impeded, resulting in lowered accuracy and prolonged RT. In other words, residual effects left by the resolution of the processing ambiguity on the previous trial (caused by concurrent presentation of two stimuli) has a negative effect on the processing of the current trial. The negative priming experimental paradigm has often been used as a tool for measuring inhibitory functioning in healthy and clinical populations, and indeed May and colleagues claim that it is “the best available index of inhibitory attentional processes” (May, Kane, & Hasher, 1995, pp 51). It should, however, be noted that some authors argue that the negative priming effect can be better accounted for by episodic memory retrieval processes rather than by inhibitory attention processes (Neill, Valdes, Terry, & Gorfein, 1992). According to this view, the presentation of a stimulus automatically evokes retrieval of similar episodes along with tags to attend or ignore the stimulus, and negative priming is seen when the currently attended item is automatically retrieved as a “do not attend” item. In a review of the negative priming literature May and colleagues (1995) found that negative priming is best accounted for by an inhibition view, while an episodic memory retrieval view may explain special cases, and they thus suggested a dual process model. In another review, Tipper (2001) found both views essentially to be about inhibition, but while one view is about inhibition of encoding, the other view is about inhibition of retrieval. Tipper thus downplayed the differences between the two views and emphasised the cognitive function of inhibition.

Another question in negative priming research is where in the perceptual flow the priming effect occurs. This question relates to whether negative priming is caused by the inhibition of specific stimulus features, which would indicate that the priming manipulates processing at an early processing level, such as perception, or whether it is caused by the inhibition of mental representations, which would indicate that the priming manipulates processing at higher cognitive levels. According to Tipper (2001), negative priming is strongest if the prime stimulus precisely matches the target stimulus (feature level). However, the effect is also present, though weaker, when the prime only matches the target on a semantic (categorical) level. Based on this finding, Tipper (2001) argued that negative priming works through two separable mechanisms.

In the current thesis, the term “negative priming” is used to describe a particular behavioural effect, namely the biasing of selection away from a repeated stimulus, observed in terms of response accuracy or RT. This bears mentioning, as the term“negative priming” is sometimes seen as being synonymous with a particular experimental set-up and a particular theoretical model for interpreting the results.

2.2.1 Negative priming and cognitive conflict

Although research on priming has typically not been approached from the theoretical context of cognitive conflict, one could nevertheless propose that both the inhibition view and the episodic retrieval view of negative priming shares properties with the concepts of cognitive control and cognitive conflict, and can be reformulated within this framework. The presentation of two simultaneous stimuli (the S^a and the S^u) can be said to activate competing states of information and cognitive control modulates lower level processing in such a way that only the instructed stimulus is attended (the task-relevant S^a), while the task-irrelevant information (the S^u) is inhibited. If a stimulus is instructed to be inhibited on one trial and to be attended on the next trial, this would increase the cognitive conflict, and this could explain the behavioural effects of negative priming mentioned above. In order to apply such a view to negative priming, it is necessary to assume that the effect of the conflict resolution on the current trial relies on the present state of the system, which is through some mechanism determined by the resolution of the conflict on the previous trial. A neural network model that would account for such mechanisms is described in section 2.2.2.

2.2.2 Neural network model of negative priming

The guided activation model of cognitive control previously presented (see section 1.3.2) can be applied to explain negative priming if one feature is added to the model:

That the processing pathways show residual effects across time, i.e., that the processing of current stimuli is determined by the processing done on the previous trial. Residual activation of the conflict detection and task-set units is a core feature of the original guided activation model (Miller & Cohen, 2001), and this feature accounts for findings such as the Gratton effect (Gratton, Coles, & Donchin, 1992). Later research, following from Jones and colleagues (Jones, Cho, Nystrom, Cohen, & Braver, 2002) also allow processing pathway units to be subject to accumulation of information and decay, in such a way that conflicts are processed differently depending on the event history. This type of residual activation of processing units has been applied to account for task-switching costs (e.g. Yeung, Nystrom, Aronson, & Cohen, 2006). By allowing residual activation also for the processing pathways, the negative priming effect can be explained thus: Simultaneously presented stimuli initiate two different processing pathways. The simultaneous activation of competing units is detected by a cognitive conflict set, and cognitive control resolves the conflict through downstream sensitivity changes. Task-demand units associates some of the information (related to the S^a) to be task-relevant and some of the information to be task-irrelevant (related to the S^u) according to the instructions given, and the cognitive control set modulates the activation of the processing pathways in order for the task-relevant information to be processed. So far the operations have been described according to the original model of Miller and Cohen (2001). The added feature in order to explain negative priming effects is that the levels of activation of the processing pathways persist beyond the duration of the trial, providing an uneven baseline for the onset of the next trial. When on the next trial the task-demand units (cognitive control) activate processing pathways that have residual increased activation from the previous trial, processing of the task-related information is facilitated, resulting in more accurate responses and shorter RT (a positive priming effect). When the task-demand units activate processing pathways with residual suppression from the previous trial, this increases cognitive conflict, and impedes processing, resulting in less accurate responses and longer RT (a negative priming effect). The application of this residual guided activation model to negative priming tasks is also explained in Figure 3.

2.2.3 Neuroimaging and lesion studies of negative priming

If negative priming can, as suggested above, be explained by mechanisms of cognitive conflict and inhibition, one would predict that the task activates pMFC and right IFG brain areas and negative priming performance should be affected in patients with medial or ventrolateral frontal cortex damage (see sections 1.3.4 and 1.3.5). Steel and colleagues (2001) used negative priming of a colour naming Stroop task in an fMRI study, and found activation of a widespread cortical network that was focused to the frontal lobes, and extended to left temporal and inferior parietal regions. However, this study was unable to conclude regarding the cognitive mechanisms involved. Egner and Hirsch (2005b) used a primed Stroop task in an fMRI study, and found negative priming to be associated with right DLPFC and right thalamus activation. In an ERP study of negative priming in the auditory domain (Mayr, Niedeggen, Buchner, & Pietrowsky, 2003), negative priming trials showed prolonged RT and a late positive complex localized to the parietal lobe. In addition, a frontal negativity was seen on the negative priming trials, but this also correlated with repetition control trials, and was thus disregarded by the authors. Metzler and Parkin (2000) found that frontal lobe lesions resulted in positive priming effects in experimental paradigms that would otherwise result in negative priming. More specifically, Stuss and colleagues (1999) found that right hemisphere lesions resulted in loss of the negative priming behavioural effect. Given that right frontal cortex is associated with inhibitory functions (see 1.2.5), the lesion studies thus appear to support an inhibition view of negative priming, while the neuroimaging studies are less consistent.

Figure 3:

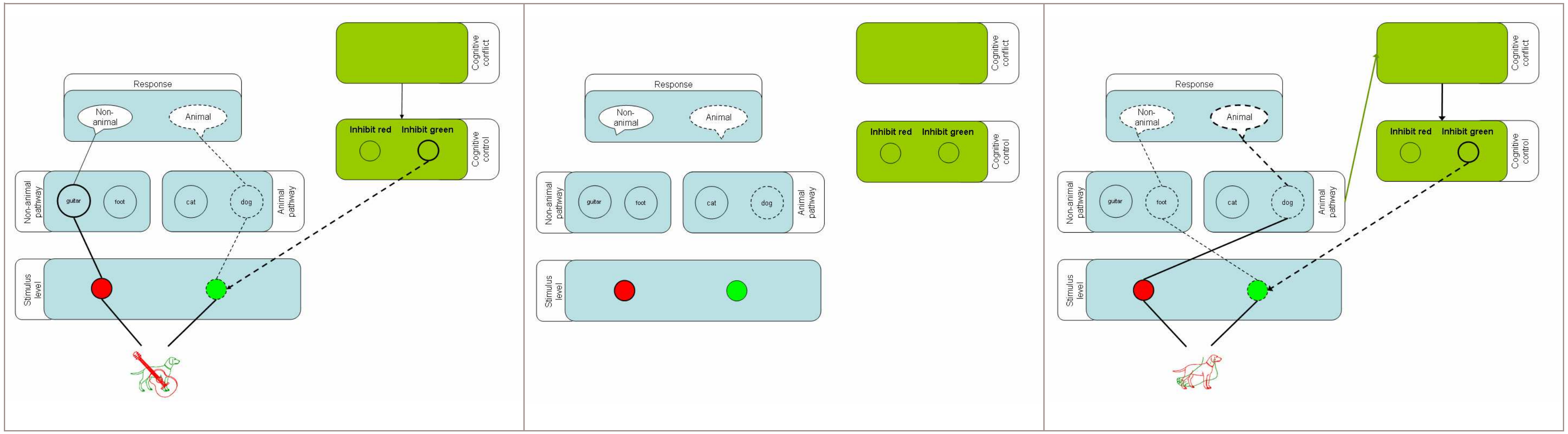
3a 3b 3c

Figure 3: The figure shows how a guided activation model with residual activation can be applied to a negative priming task. The participant is instructed to report whether or not the red image is an animal. Figure 3a shows how on trial^{n} (an unprimed trial), cognitive control resolves the ambiguous figure through giving the unattended stimulus (S^{u} – the dog) a relative processing disadvantage (inhibition, indicated by dashed lines) compared to the attended stimulus (S^{a} – the guitar). Figure 3b shows the state of the network before the onset of the trial^{n+1}, where the information associated with S^{u} on trial^{n} shows residual suppression. Figure 3c shows the processing elicited on trial^{n+1} (a negative priming trial), where the current S^{a} (the dog) matches the S^{u} on trial^{n}. One of the processing pathways is activated by representing the S^{a} on trial^{n+1} while being inhibited by the residual activation from trial^{n}, leading to increased cognitive conflict and behavioural negative priming effects.

3. Dichotic listening

3.1 Hemisphere asymmetry and language functions

Galaburda (1995) stated that despite evident functional asymmetry between the two hemispheres, there is little evidence for differences between the hemispheres in the sense that neuronal connectivity, cell types or neurotransmitter systems vary between the hemispheres. There are, however, anatomical differences between the hemispheres in the sense that grey matter density varies for specific brain areas. One of the best examples of this is the asymmetry of grey matter density in the planum temporale area in the upper posterior part of the temporal lobe. The planum temporale area is larger on the left side, as revealed in both autopsy studies (Galaburda, 1987; Geschwind, 1968) and MR morphometry (Heiervang et al., 2000; Jäncke, Schlaug, Huang, & Steinmetz, 1994).

This anatomical difference appears to reflect the functional lateralization of speech perception to the left hemisphere (Geschwind, 1979). The area covered by the planum temporale overlaps with Wernicke’s area, which is a functional area responsible for speech perception and comprehension, located just posterior to the primary auditory cortex. Functional neuroimaging studies have shown that while the bilateral auditory cortex is activated by auditory stimuli, the left planum temporale is more strongly activated by speech sounds. This has been shown by experiments using neuroimaging with both positron emission tomography (PET - Hugdahl et al., 1999) and fMRI (Thomsen, Rimol, Ersland, & Hugdahl, 2004), and by ERPs (Eichele, Nordby, Rimol, & Hugdahl, 2005; Jäncke & Steinmetz, 1993).

3.2 The dichotic listening experimental paradigm

The term dichotic listening implies that a person is presented with two different sounds at the same time, one presented in the left ear, the other in the right ear. Cognitive psychology experiments (Broadbent, 1954; Cherry, 1953) have established that when participants perform the dichotic listening task, the stimulus from one channel (ear) is processed earlier or to a fuller extent than stimulus from the other channel. Hence, the dichotic listening situation is a classical example of what Broadbent (1957; 1958) referred to as a processing bottleneck. In the years since the classic experiments in the 1950ies, cognitive research has focused on where in the processing stream the bottleneck is located, or to which extent it is an absolute cut-off, i.e. to what extent the unattended stimulus is processed (see Deutsch & Deutsch, 1963; N. Wood & Cowan, 1995). Another branch of research has focused on examining which factors determine whether the left or right signal is reported, and to what extent this can be modulated by situational or individual factors (Hugdahl, 2003).

3.3 Experimental variations of the dichotic listening task

It has been shown that procedural aspects the stimulus presentation influence performance in the dichotic listening paradigm. For example, when the presentation of one of the dichotic stimuli is delayed, the delayed stimulus is more likely to be reported (Berlin et al., 1973; Studdert-Kennedy, Shankweiler, & Schulman, 1970). Recent studies have explored what effect changing the interaural stimulus intensity has on which stimulus is reported (Hugdahl, Westerhausen, Alho, Medvedev, & Hämäläinen, 2008; Tallus, Hugdahl, Alho, Medvedev, & Hamalainen, 2007). Moreover, Rimol and colleagues (Rimol, Eichele, & Hugdahl, 2006; Rimol, Specht, Weis, Savoy, & Hugdahl, 2005) have shown that when a voiced consonant-vowel (CV) syllable is presented in one ear and an unvoiced syllable in the other ear, the participants tend to select the voiced syllable. It has also been shown that simultaneous presentation of a video pronouncing one of the syllables biases the reporting (Sætrevik & Hugdahl, in preparation).

When using verbal stimuli, the typical finding in the dichotic listening situation is the so-called right ear advantage (REA), which means more items are correctly recalled from the right ear than from left ear in a free recall situation (Hiscock, Cole, Benthall, Carlson, & Ricketts, 2000; Hugdahl, Helland, Faerevaag, Lyssand, & Asbjornsen, 1995). Alternative explanations for the REA are discussed below (see section 3.4.1 and 3.4.3). Several authors (e.g. Asbjornsen & Bryden, 1996; Bryden, Munhall, & Allard, 1983; Gadea, Gomez, & Espert, 2000; Hiscock & Stewart, 1984; Hugdahl & Andersson, 1986) have reported that the REA can be either increased or decreased by explicitly instructing the participant to focus attention on the right or the left ear stimulus. A standardised version of this experiment procedure was called the "forced-attention dichotic listening" paradigm by Hugdahl and Andersson (1986).

3.4 Theoretical models of dichotic listening

As mentioned above, there is a baseline REA in dichotic listening with verbal stimuli, and it has been shown that this baseline can be modulated by instructions to attend to one side. There are four main models that attempt to account for the REA and for the modulation of the REA.

3.4.1 The structural model

The "structural model" (Kimura, 1967) stated that the REA is caused by lateralized speech processing and the crossing over of the auditory fibres from the cochlea to the auditory nuclei in the inferior colliculus and medial geniculate body. This causes signals to be transmitted more directly to the temporal lobe contralateral to the input through the brainstem and midbrain, while for the signal to reach the temporal lobe ipsilateral of the input, the signal has to be transmitted from the contralateral hemisphere through the corpus callosum. An illustration of this is shown in Figure 4. From this it follows that when the task is to report what is heard first or best, the information initially available to the left temporal lobe language areas comes more strongly from the right (contralateral) ear. The REA can thus be explained as a bottom-up effect.

Figure 4:

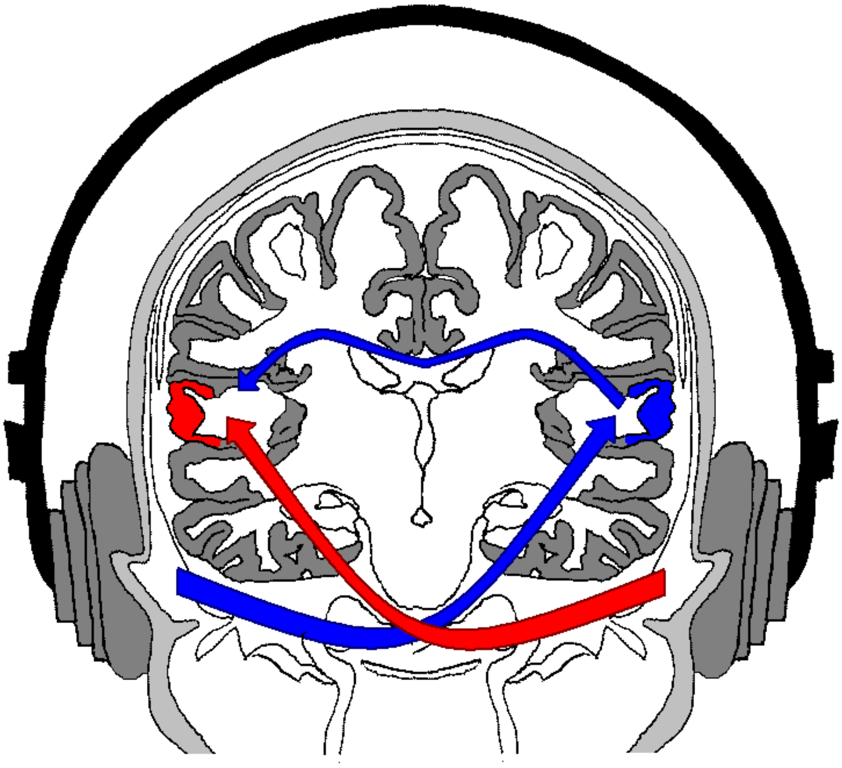

Figure 4: A schematic model showing how left hemisphere has better access to right ear information, due to structural features.

3.4.2 Top-down modulation of bottom-up laterality

It has been shown that the amplitude of the baseline REA for verbal stimuli in dichotic listening can be modulated when participants are instructed to direct their attention to the left or the right ear. However, Hugdahl and co-workers (Hugdahl, 2003; Hugdahl, Lundervoll, von Plessen, Heiervang, & Rimol, 2004) have suggested that the modulation is not symmetrical: Attention to the right ear stimulus produces more correct right ear answers than attending to the left ear stimulus produces correct left ear answers. Moreover, it has been shown that patients with impaired or deficient frontal cortex function, such as e.g. patients with schizophrenia, more often fail to report the left ear stimulus when instructed to attend the left side than they fail to report right ear stimulus when instructed to attend the right side (Hugdahl, Lundervoll, von Plessen, Heiervang, & Rimol, 2004; Løberg, Hugdahl, & Green, 1999). Hugdahl has proposed a model where a baseline REA produced by bottom-up structural features is modulated by a top-down attentional mechanism (Hugdahl, 2003). The two processes work in parallel and have an additive function resulting in the asymmetrical effect. This model has been supported by neuroimaging results (Thomsen, Rimol, Ersland, & Hugdahl, 2004), that showed that compared to binaural listening, dichotic listening increased PFC activation and activation of left temporal lobe perceptual areas (see Figure 5). Further, adding the "forced-attention" manipulation had the effect of increasing PFC activation to a larger extent than temporal lobe activation, suggesting that the attention modulation works through attention selection rather than through increasing perceptual sensitivity.

3.4.3 Hemispheric activation model

Kinsbourne (1970; 1973; 1975) suggested that the observable asymmetries in processing of auditory and visual stimuli is due to preponderant activation of one hemisphere that causes attention to be directed at the contralateral side in extrapersonal space. When expecting verbal stimuli, the left hemisphere is more activated than the right hemisphere. This difference in activation between the hemispheres creates an attentional bias in early perception of stimuli. Kinsbourne (1970) showed that performing a consecutive verbal working memory task increased detection of right-sided gaps in a gap detection task. In the case of dichotic listening, participants are expecting verbal stimuli, and at the presentation of the stimuli, the left hemisphere is therefore more activated than the right hemisphere, causing an attentional bias which facilitates perception of the right ear signal, thus producing the REA. Kinsbourne's model is thus a stimulus driven top-down attentional approach to explain the baseline REA, as opposed to Kimura's bottom-up structural approach.

Figure 5.

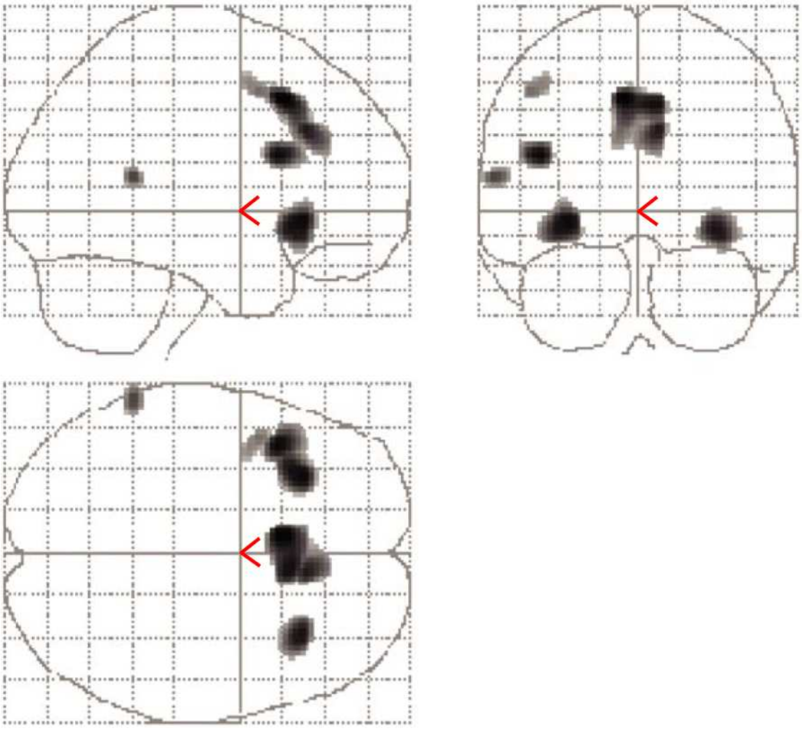

Figure 5: fMRI results from a study using the directed attention dichotic listening task (Thomsen, Rimol, Ersland, & Hugdahl, 2004) showed that dichotic presentations produce more PFC and left temporal lobe activation than binaural presentations does.

3.4.4 Two-stage model

Hiscock and colleagues (Hiscock, 1980; Hiscock, Inch, & Kinsbourne, 1999) proposed a two-stage model for selective listening in which the first stage is fast and automatic, while the second is slow and controlled. The first stage of signal processing is asymmetric, which accounts for the baseline REA on recall tasks, and for a higher accuracy for detecting targets presented in the right ear on detection tasks. This baseline asymmetry may be due to a bottom-up structural influence, as in Kimura’s model (1967), or it may be due to a top-down attentional process, as in Kinsbourne’s model (1975). According to Hiscock and colleagues (Hiscock, Inch, & Kinsbourne, 1999), this issue is not yet settled and neither can it be settled by an experimental approach. The second stage of the processing is slow and controlled, and represents selective attention. The second stage processing has the output from the first stage as its input, and thus starts out with a lateral asymmetry. When instructions do not direct attention, the second-stage attention selection is biased by the first stage REA asymmetry, which has the effect of automatically increasing right side localizations and detections, thus further enhancing the REA.

In a study designed to test this model, Hiscock and colleagues (Hiscock, Inch, & Kinsbourne, 1999) used CV syllables and fused-word stimuli, and asked participants to detect a given target for each trial, and to localize the target to the left or right ear. The target identity was revealed before or after stimulus presentation for each trial. The argument that there are two distinct processing stages, and that some selection happens at early stages, while other selection happens at later (cognitively higher) processing stages was supported by the fact that whether the identity of the target was disclosed before or after the stimulus presentation did not affect the accuracy of the target detection. Results further showed that focusing attention to one side enhanced target localization, but had no significant effect on target detection. This was due to the participants recognizing the targets equally well regardless of whether the sound was presented in the attended or the unattended ear, but on some trials the participants nevertheless misattributed the sounds as coming from a different ear. From this the authors argued that attention shifts occur at the response selection stage rather than at the perceptual processing phase.

3.5 Dichotic listening as cognitive conflict

It could be argued that the dichotic listening task satisfies the criteria suggested by Botvinick and colleagues (Botvinick, Braver, Barch, Carter, & Cohen, 2001) for situations that cause cognitive conflict. Two stimuli are presented at the same time, and either one of the two stimuli are equally correct as response. This constitutes an underdetermined situation, which according to the theoretical framework of Botvinick and colleges should increase cognitive conflict. In order to resolve the conflict, a selection between the stimuli has to be made, either on a perceptual level, in which case the participant will only become fully aware of one of the stimuli, or on an attentional level, in which case the participant will to a larger extent be aware of both stimuli. The theoretical models of dichotic listening reviewed above could be seen as various ways in which the cognitive conflict may be resolved. The REA is caused by the right ear stimulus being a more salient signal (either due to structural features or an early attention bias), and thus causes the cognitive conflict to be resolved in favour of the right ear signal in the absence of instructions. This would be analogous to how word reading is the preponderant response in the Stroop task (see section 1.3.2). When instructions focus attention on the right ear, the cognitive control emphasizes the processing of a different stimulus than what would otherwise be processed, thus increasing the cognitive conflict.

The "forced-attention dichotic listening" could also be compared to negative priming experiments in the auditory domain, as both types of experiments present sequential pairs of two simultaneous stimuli, one in each ear, and the participant is asked to report the identity of the stimuli in one specified ear. The two types of experiments may thus have similarities, at least in terms of experimental design. Indeed, in a review of selective attention research Driver (2001) introduces Tipper's negative priming experiment (1985) as an extension of Broadbent's dichotic listening tradition (1957; 1958) into the visual domain. Attending to or inhibiting a stimulus in dichotic listening may thus have consequences for subsequent processing, in the same way as has been shown in negative priming experiments. It could thus be of interest to explore the dichotic listening experimental paradigm also to examine for negative priming effects.

4. Primed dichotic listening

The dichotic listening experiment presents an interesting perspective for studying cognitive control, as it provides two auditory inputs and requires selection of one of the inputs as a response. Further, it has been shown that using attentional instructions to manipulate the participant's intention to attend to one side modulates the responses in dichotic listening.

4.1.1 Limitations of directed attention accounts of dichotic listening

The ”forced-attention dichotic listening” experiment has been shown to distinguish between clinical groups, in the sense that patients with attentional and executive dysfunctions show decreased ability to direct attention according to instructions (Hugdahl et al., 2003; Løberg, Jørgensen, & Hugdahl, 2004). It has further been argued that directing attention to the left activates different attention functions than directing attention to the right (Hugdahl et al., 2003). However, the “forced-attention dichotic listening” experiment has some inherent restrictions. After instructing the participant to attend to one side, the experiment relies on the participant’s motivation and level of vigilance, and there is no way to determine the extent to which the attention is in fact directed, and whether attention is directed to the same degree throughout the duration of the experiment. Differences in performance between groups may therefore be confounded with differences in the capacity to understand or adhere to the instructions. It would therefore be of importance to develop an alternative way of modulating attention in dichotic listening that avoids the limitations of task instructions.

4.1.2 Priming applied to dichotic listening

An alternative to the “forced-attention dichotic listening” would be to use priming stimuli, as explained above (see section 2). A binaural prime stimulus that participants are instructed to ignore could be presented immediately before the dichotic stimuli. On some trials the prime stimulus could be the same as one of the dichotic stimuli (“matching prime” trials), and one would observe whether the primed or the unprimed stimulus from the dichotic stimulus pair was more frequently reported on these trials. However, the presence of a priming effect would not necessarily indicate attention modulation, as a priming effect could also be caused by bottom-up mechanisms. One would have to argue from behavioural and neuroimaging data that the experimental task does indeed manipulate attention.

4.2 Theoretical model for primed dichotic listening

The research question of the current thesis thus relate to whether or not the experimental manipulation of priming can be applied to a dichotic listening task. What would the behavioural effects be, would priming of dichotic listening result in positive or negative priming effects? Within which theoretical model should the priming effects be understood? Which neuroanatomical structures would be involved in responding to the task?

4.2.1 Priming understood as a bottom-up or a top-down process

Facilitating priming effects in dichotic listening, that is, when priming increases reports of the primed dichotic stimulus (positive priming), would most easily be accounted for by a bottom-up spreading activation model (see section 2.1). The presentation of a prime stimulus would activate the corresponding neural population, and for some duration after the prime presentation the threshold for the same network to be reactivated would be lower, thus allowing the primed dichotic stimulus to "win the race" against the unprimed dichotic stimulus. On the other hand, a situation where priming is shown to have an impeding effect on subsequent dichotic listening processing, that is, when the priming stimulus causes creased reports of the primed dichotic stimulus (negative priming), would be more difficult to account for by bottom-up processes, and may be best accounted for by top-down processes, given that alternative bottom-up accounts such as habituation or pop-out effects have been excluded by experimental control. One such top-down account could be through cognitive conflict and inhibition, as outlined below.

4.2.2 Cognitive conflict in primed dichotic listening

For each trial in a primed dichotic listening paradigm, processing pathways of the prime stimulus and of both left and right dichotic stimuli would potentially be activated. The processing pathways are competitive, and would thus present the potential for cognitive conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Given no task instruction, one would assume that the processing pathway corresponding to the binaural prime stimulus would be more strongly activated than the representations corresponding to the ambiguously presented dichotic stimuli. When the task instructions call for ignoring the salient signal of the prime and attending the dichotic pair, which is an ambiguous, weak signal, cognitive control would thus appear necessary to perform the task (Miller & Cohen, 2001). In addition, on “matching prime” trials one of the stimuli is both task-irrelevant (for being the prime stimulus) and task-relevant (for being part of the dichotic stimuli). One would thus expect more conflict on “matching prime” trials than on “non-matching prime” trials due to this overlap between task-relevant and task-irrelevant information (Miller & Cohen, 2001).

4.2.3 Inhibition model of primed dichotic listening

An inhibition model may be proposed, in which the cognitive conflict caused by primed dichotic listening is resolved by cognitive control inhibiting the task-irrelevant information (the prime stimulus). On “matching prime” trials, there is overlap between task-relevant and task-irrelevant information, which increases the conflict and requires additional inhibitory resources. If the task is solved through inhibition of the prime, the inhibition may have a carry over effect in inhibiting the primed dichotic stimulus on the “matching prime” trials, thus having the effect of facilitating the processing of the unprimed stimulus. In other words, the residual effect of an inhibition of the prime representation biases the processing of the dichotic target stimuli, thus causing a negative priming effect. For a chronological overview of the cognitive operations involved in solving the task, see Figure 6.

4.2.4 Neural network model for primed dichotic listening

The model outlined above can be reformulated in neural network terms. This would constitute a guided activation model of cognitive control along the lines of the model proposed by Cohen and colleagues (see section 1.3.2) to account for the Stroop task, and the model introduced previously to account for the behavioural effect in negative priming experiments (see section 2.2.2). The proposed model postulates that prime

Figure 6:

Experimental task	Cognitive operations
Binaural prime syllable presented	Task-irrelevant information inhibited
Dichotic syllable presented	Task-relevant information attended
	If there is overlap between task-relevant and task-irrelevant information, cognitive conflict increases
	Additional inhibition resolves conflict in order to select a response
Response selected	

Figure 6: A chronological overview of the cognitive operations assumed to be elicited by the experimental task for each trial.

stimulus and dichotic target stimuli are processed by separate sets of units, and that these sets are connected to a higher level set of units representing the response alternatives. Although the presented model postulates separate sets for prime stimulus and dichotic stimuli, the neural implementation of prime and dichotic stimuli may happen in the same neural population, but temporally separated. For an overview of the model, see Figure 7. Three competing stimuli presented closely together in time incite competitive response units, and downstream modulation of the processing pathways is necessary in order for the system to reach a single output. To resolve this conflict in accordance with the instructions, cognitive control assigns the prime stimulus information to be task-irrelevant, and negative feedback therefore reduces activation for that stimulus's processing pathway (relative to competing pathways).

On "matching prime" trials the processing of a stimulus is initially suppressed, due to being the task-irrelevant prime, and immediately thereafter is to be attended, due to being task-relevant as part of the dichotic pair. This contradictory activation

Figure 7:

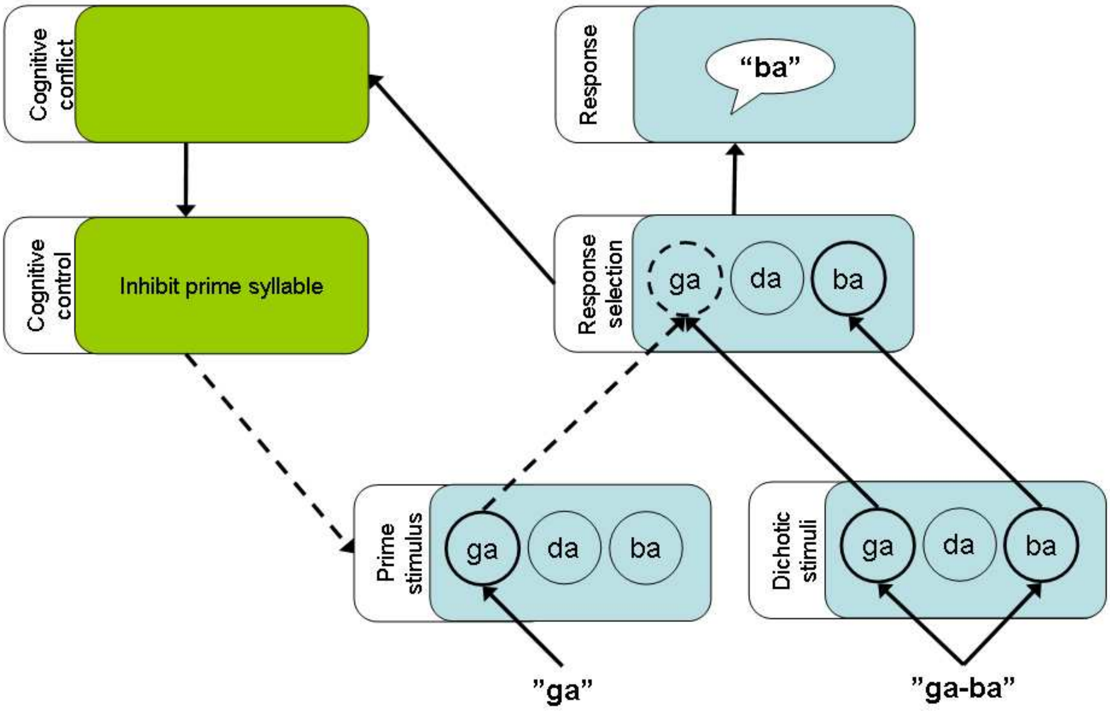

Figure 7: The figure shows a sketch of a neural network model proposed to account for the primed dichotic listening effect. The prime stimulus and the dichotic stimuli are initially processed in separate sets, before the activation is forwarded to a higher level set (shown with solid lines). A cognitive control set causes a relative processing suppression of the prime stimulus unit in the response selection set (shown with dashed lines). On "matching prime" trials, the response selection unit representing the primed syllable thus receives both excitatory and suppressive input, while the unit representing the unprimed syllable receives only excitatory input. This causes the unit representing the unprimed syllable to be more activated, causing this syllable to be selected as response, thus causing the observable negative priming effects. Activation of more than one unit and contradictory inputs on the response selection set increases activation of the cognitive conflict set, which has an excitatory effect on the cognitive control set.

input for a unit causes the level of cognitive conflict to increase, and the increase in cognitive conflict leads to an increase in cognitive control. At the response selection level, units for both of the dichotic stimuli are in competition, so if one of the units is suppressed due to matching the prime, this biases the subsequent competition, and increases the probability for the unprimed stimulus to be selected.

4.2.5 Neuroanatomical predictions for primed dichotic listening

According to Botvinick and colleagues (Botvinick, Braver, Barch, Carter, & Cohen, 2001), a cognitive conflict model for task behaviour would require one mechanism for detecting conflict and one mechanism for resolving the conflict. Compared to the “non-matching prime” trials, the ”matching prime” trials would be expected to increase activation of a mechanism for detecting cognitive conflict and for a mechanism for resolving the conflict. The cognitive control associated with attempting to perform the task according to the restrictions of task instructions is typically assumed to be instantiated in DLPFC (see section 1.3.4). Conflict detection has been proposed to be instantiated in pMFC. Once detected, the conflict could be resolved by inhibition of the processing pathway that matches the prime stimulus, which would account for a negative priming effect. Lesion, perturbation and neuroimaging studies have indicated that right IFG is necessary for inhibition (see 1.3.4). As the task instructions are stable across the experiment, one may not expect to see the involvement of cognitive control vary between the experimental conditions. However, cognitive control should influence which response is selected on the trial, so one may expect the amount of DLPFC activation to be associated with the response categories. In connecting these cognitive terms to the neural network model outlined in section 4.2.4, reiterated activation (caused by the cognitive conflict) would be represented by pMFC, while negative feedback could be represented by right IFG activation (inhibition), and task-demand units could be represented by DLPFC activation (cognitive control). See Table 1 for the theoretical model expressed at various explanatory levels. As an alternative to the approach used in the current work, one could have examined whether the amount of control on a trial was associated with the amount of conflict on the preceding trial, along the lines of what was done for the Gratton effect (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Gratton, Coles, & Donchin, 1992; MacDonald, Cohen, Stenger, & Carter, 2000).

Table 1:

Functional level	**Attentional system level**	**Neural network level**	**Response level**	**Anatomical area involved**	**Increased activation for ”matching prime” compared to ”non-matching prime” trials?**	**Increased activation for ”matching prime” condition where unprimed stimulus is selected?**	**Increased activation for ”matching prime” condition where primed stimulus is selected?**
Solve task according to instructions (attend task-relevant information, ignore task-irrelevant information, respond with stimulus from the dichotic pair)	Cognitive control	Task-demand units in cognitive control set discern task-relevant aspects from task-irrelevant aspects of the context	Priming adds cognitive processes that influence response selection and RT compared to dichotic listening without priming (this comparison was not tested)	DLPFC	No – Active throughout task, no difference between stimulus conditions	Yes – More cognitive control on the trials where the response alternative matching only the task-relevant information is selected	No – Less cognitive control on trials where the response alternative matching the task-irrelevant information is selected
Detect whether there is incompatible information	Cognitive conflict	Reiterating activation in lower level processing when attempting to reach stable state activates cognitive conflict set	”Matching prime” condition has additional conflict which increases the RT	pMFC	Yes – “Matching prime” condition creates more conflict	No – Conflict is reduced when inhibition solves the conflict	Yes – More conflict when inhibition does not solve the conflict
Suppress task-irrelevant information in order for task-relevant information to be processed	Inhibition	Negative feedback set adjusting lower level processing in order to reach a stable state	Inhibition resolves the conflict, thus influencing the response selection and decreasing the RT	Right IFG	Yes – Inhibition is applied more often for the ”matching prime” trials	Yes – Inhibition is to a larger extent applied on these trials	No – Inhibition is to less extent applied on these trials

Table 1: A summary of the theoretical model proposed to predict behavioural and neuroimaging effects of the primed dichotic listening task. The theoretical model is presented in terms of the function of each mechanism, in attentional terms, in terms of the neural network operations performed, predictions for behavioural measures and the neuroanatomical areas assumed to be involved. The final three columns are predictions of under which circumstances each mechanism should show increased activation (to be compared with the three BOLD-fMRI comparisons in Report III).

5. Summary of reports

5.1 Research questions

5.1.1 Report I

The research questions of Report I was whether the responses in dichotic listening could be manipulated by priming. Would the effect of a prime be excitatory or inhibitory? Would the priming effect show an interaction with the baseline REA? Would priming only have an effect when the prime stimulus is in the same sensory modality as the dichotic stimuli is presented, which would support an early perceptual, bottom-up account of the effect, or would priming have an effect cross-modally, which would indicate an effect at a higher cognitive level, and would indicate the presence of a top-down mechanism?

5.1.2 Report II

There were two research questions of Report II: First, can the priming manipulation of Report I be combined with the instruction manipulation of the “forced-attention dichotic listening” situation? Second, would the results show an interaction between the two types of manipulations? Such an interaction would imply that the cognitive mechanisms involved in the two types of modulation of responses share resources at the same cognitive level.

5.1.3 Report III

Based on the theoretical model presented above (section 4.2.2, 4.2.3 and 4.2.4), the research question of Report III was whether the ”matching prime” condition would increase cognitive conflict compared to the ”non-matching prime” condition, which would be seen as increased activation of the pMFC. A further question was whether the effect of priming on response selection was caused by inhibition elicited to resolve the conflict, which would be seen as increased activation of the right IFG.

5.2 Methods

5.2.1 Experimental design

The three reports used the same basic experimental design. Each trial presented a dichotic syllable pair, consisting of the simultaneous presentation of different syllables in the right and left ear. The syllables used were six consonant-vowel combinations (/ba/da/ga/pa/ta/ka/), paired into 30 non-homonymic syllable pairs, such as /ga-ba/, where /ga/ was presented in the left ear, and /ba/ was presented in the right ear. So far the experimental set-up is similar to the standard CV-syllable dichotic listening paradigm used in numerous experiments (e.g. Hugdahl, 1995; Hugdahl, 2003; Hugdahl & Andersson, 1986; Hugdahl, Bodner, Weiss, & Benke, 2003; Jäncke, Mirzazade, & Shah, 1999; Jäncke & Shah, 2002; Thomsen, Rimol, Ersland, & Hugdahl, 2004). In addition to the standard dichotic listening procedure, a prime syllable was presented binaurally with onset 1 s before the onset of the dichotic syllable pair. In the second experiment of Report I, the prime stimulus was instead presented as text on a PC screen in front of the participant. After the offset of the dichotic CV-pairs, a response screen appeared that displayed the six possible response alternatives (corresponding to the six CV-syllables), and the participants selected the syllable they had heard best from the dichotic pair. The position of the response alternatives on screen was permutated between participants. See Figure 8 for a schematic display of the experimental procedure.

5.2.2 Experimental conditions and response categories

Half the trials were ”non-matching prime” trials (labelled "unprimed trials" in Report I and II), while the remaining half of the trials were “matching prime” trials (labelled "primed trials" in Report I and II). On a ”non-matching prime” trial, the prime syllable was one of the four syllables that was not part of the following dichotic pair. On a “matching prime” trial, the prime syllable was the same as one of the dichotic syllables. In Report I and II, the “matching prime” condition was further split into trials where the prime matched the left dichotic syllable ("prime-left" condition) and

Figure 8:

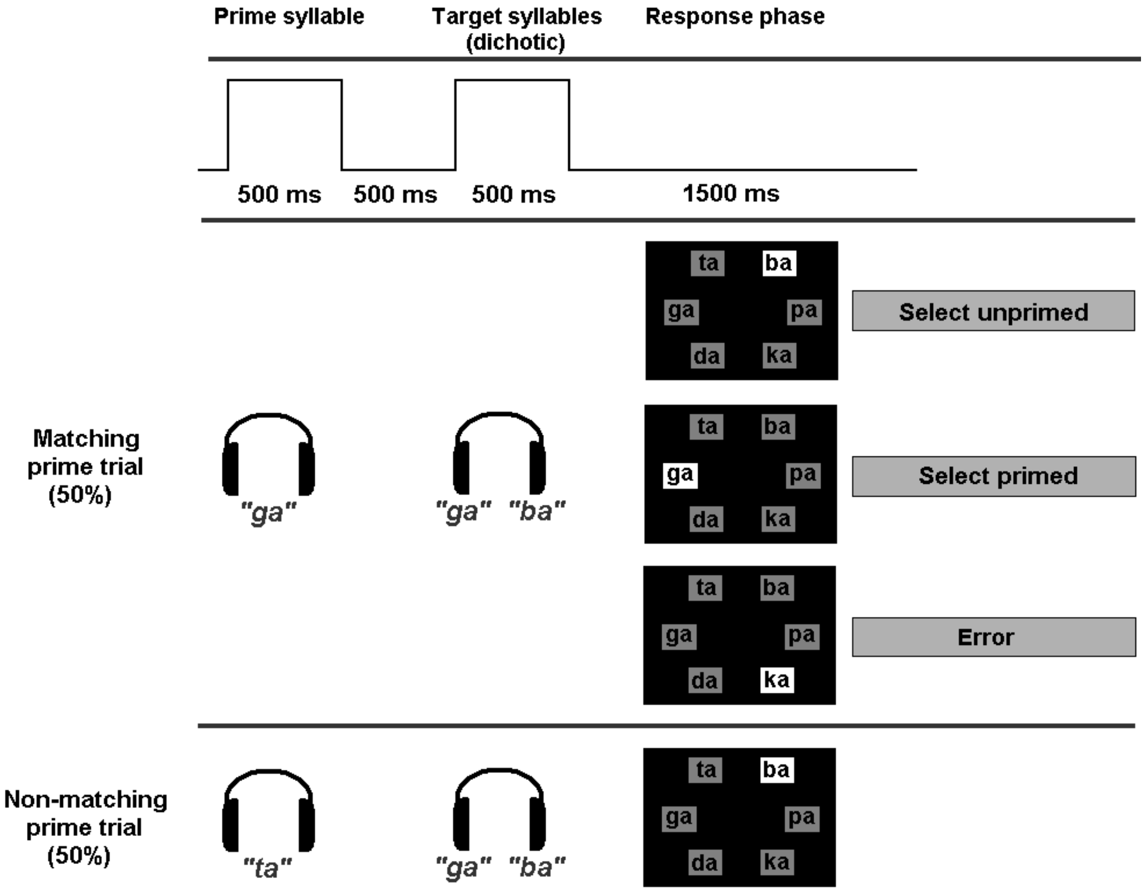

Figure 8: A schematic display of the experimental procedure used in all reports (note that experiment 2 in Report I had prime in the visual, not auditory modality). The correspondence between prime syllable and dichotic syllables divided trials into "matching prime" trial and "non-matching prime" trial conditions. The correspondence between the prime syllable and the syllable selected as response divided the "matching prime" trials further into three response categories.

trials where the prime matched the right dichotic syllable ("prime-right" condition). The divisions between "prime-left" and "prime-right" were collapsed in Report III.

In addition to sorting trials into conditions based on stimulus relationships, the "matching prime" condition trials were further divided based on response category. In Report I and II, responses were divided into "left ear responded" or "right ear responded" according to whether the response correctly reflected the left or right dichotic syllable. The effect of priming could thus in Report I and II be seen by comparing the laterality of responses in the "prime-left" condition with the laterality of responses in the "prime-right" condition. To simplify the presentation of results, the scores were converted into a laterality index score in Report II, based on the right minus left ear scores divided by the overall score. For Report II and III, ”matching prime” trial responses were categorized according to whether the selected syllable matched the prime syllable or not. Trials where the participant’s response was the same as the prime syllable of that trial were labelled “select primed” trials (these trials were in Report II labelled “responded with the primed syllable”). Trials where the dichotic syllable that was different from the prime was responded were labelled “select unprimed” trials (these trials were in Report II labelled “responded with the unprimed syllable”). See Figure 8 for examples of the response categories. The effect of priming could thus in Report II and III be seen by comparing the relative frequency of “select primed” and “select unprimed” trials in the “matching prime” condition. To simplify the presentation of results, these two scores were converted into a “priming index” score in Report II, based on the “select primed” scores minus “select unprimed” scores divided by the overall score.

5.2.3 Variations between the experiments

All experiments employed the same stimulus material and stimulus relationships, but there were slight variations in the instructions given. In both experiments in Report I, the participants were instructed to attend to both the prime and dichotic syllables, and a cue after the dichotic syllables indicated whether the prime or one of the dichotic syllables should be reported. Trials where prime reporting was requested were considered to be catch trials, and were not further analyzed. In the experiment in Report II and III, participants were instructed on all trials to to ignore the prime and attend to and report the syllable perceived best from the dichotic syllables. In the second and third experiment blocks of Report II, participants were instructed to focus attention on either the right or left ear stimulus in the dichotic pair, and to report only from the attended ear. Responses were given with mouse pointing in Report I and II, and with response buttons in Report III.

5.3 Summary of results

5.3.1 Report I

The first report, *Priming inhibits the right ear advantage in dichotic listening*, showed that when a binaural syllable that matches one of the dichotic syllables was presented immediately before the dichotic pair (the primed trials), the number of reports of the primed syllable decreased (a negative priming effect). The effect was seen both when the priming was done with an auditory prime stimulus (the first experiment) and when the priming was done visually (the second experiment). The priming effect was symmetrical, in the sense that priming of left and right ear stimuli had the same effect.

In Report I, the effect of priming was reported in terms of changing the laterality of responses when the prime matched right or left syllable. Given that the priming effect was symmetrical, an alternative (and perhaps preferable) way of measuring the effect would be in terms of relative frequency of “select primed” and “select unprimed” responses (as was done in Report II and Report III).

The priming effect was accounted for as a top-down attention inhibition effect: The prime syllable is initially a more salient signal than the dichotic stimuli. Cognitive control is necessary to suppress the processing of the prime in order to process the dichotic stimuli. The dichotic stimuli activate two different processing pathways, and when one of the pathways is inhibited due to matching the task-irrelevant prime, this causes the other syllable to be reported. The fact that the priming effect was symmetrical, and thus did not interact with the baseline REA, indicated that the mechanism that causes the priming effect is not located on the same level as the mechanism causing the REA. The fact that the effect was cross-modal further supported a top-down account.

5.3.2 Report II

The second report, *Endogenous and exogenous control of attention in dichotic listening*, used the same design as the first experiment in Report I combined with the instruction modulation from the “forced-attention dichotic listening” paradigm. The results showed an overall priming effect and an overall directed attention effect. Furthermore, there was an interaction effect indicating that the priming effect was contingent on whether the direction of attention went in the same or the opposite direction as the priming direction.

This experiment showed that the two ways of manipulating the dichotic listening responses could be combined. Furthermore, the interaction effect between the two types of manipulations indicated that the cognitive mechanisms involved share cognitive resources, and thus further supported the claim that the priming effect is due to a top-down process modulating attention.

5.3.3 Report III

The third report, *An fMRI study of priming in dichotic listening shows inhibition of attention*, repeated the experimental design used in Report I, while also acquiring fMRI data for analysis of neuronal activation correlates to the experimental design and behavioural data. The same behavioural effect was found as in Report I and II. There was an RT effect of faster responses when selecting the unprimed rather than the primed syllable on the “matching prime” trials.

Comparisons between ”matching prime” and ”non-matching prime” stimulus conditions showed neuronal activation in the pMFC and in the right IFG. This was explained as the matching prime increasing the cognitive conflict, and an inhibitory mechanism being recruited to resolve the conflict. Two additional parametric contrasts were done between the trials from the ”matching prime” condition, depending on whether the unprimed or the primed syllable was selected. These contrasts were assumed to represent to which extent the primed syllable had been inhibited. The first parametric contrast showed that there was a significant increase in activation in DLPFC and in right IFG for trials where the unprimed syllable was selected. This was explained as activation of the DLPFC representing increased cognitive control while activation of the right IFG representing increased inhibition in order to resolve the conflict. The second parametric contrast showed that there was an increase in activation in the pMFC and left IFG for trials when the primed syllable was selected. This was explained as conflict increasing and the response being selected through other approaches when the conflict was not resolved through inhibition.

The findings from Report III thus indicated that the task activates pMFC and right IFG corresponding to mechanisms for cognitive control and for inhibition, respectively. Along with the RT effects, this supported the argument that the behavioural results in Reports I, II and III were caused by an attention inhibition mechanism producing a selection of the unprimed syllable.

5.3.4 Errata

The correct number of participants in Report I was 19 for experiment I and 22 for experiment II. The analyses, figures and degrees of freedom reported in the paper are based on the correct number of participants.

Due to an error, the stimulus presentation mode in Report I was described as “monaural”, it should have been “binaural”

6. Discussion

6.1 Implications for primed dichotic listening

The three reports demonstrated a novel way of manipulating responses in the dichotic listening paradigm, which appears to act through attention inhibition. The effect of priming appears to be robust across variations in the experimental procedure. A model to account for the priming effect was proposed, according to which cognitive conflict is increased by the priming, and cognitive control recruits inhibitory mechanisms to resolve the conflict. Such a top-down account was supported by the cross-modal results, by the interaction with attention instruction manipulations, and by PFC activations in the fMRI study. The thesis thus presents an alternative approach to testing attentional functions that bypasses some of the limitations of “forced-attention dichotic listening” (see 4.1.1).

6.2 Implications for dichotic listening models

All four of the primed dichotic listening experiments replicated the REA for verbal stimuli when conditions were collapsed. This indicates that despite adding experimental variations to the dichotic listening experiment, the primed dichotic listening task still reflects language processing. There was no interaction between REA and priming, i.e. there was no asymmetry in the priming manipulation, in the sense that the prime was equally effective whether the left or right ear syllable was primed. Given that the priming appears to be a top-down attention effect, this supports the view of the REA as being caused by an early perceptual effect, as argued by Kimura (1967) and Hugdahl (2000), rather than a top-down attentional effect as argued by Kinsbourne (1973; 1975), in which case one would expect to see asymmetric priming effects.

Further, as the finding in Report II showed that the priming does interact with attention instructions, this supports the proposition that the attention instruction manipulation in the “forced-attention dichotic listening” task is a late stage mechanism that relies on cognitive control, rather than a mechanism that increases the perceptual sensitivity of one ear. This is supported by Thomsen and colleagues (2004), who found that attention instructions modulated prefrontal activation to a larger extent than it modulated temporal activation. Given that Report II showed that the priming manipulation interacts with the manipulation of attention instructions, one may assume that to some extent the same cognitive operations are involved in the priming effect as are involved in the instructed attention effect. This is supported by comparing the neuroanatomical areas found to be activated by the priming in Report III to the areas activated in a “forced-attention dichotic listening” task (Thomsen, Rimol, Ersland, & Hugdahl, 2004), which to some extent reveals the same PFC network. This is discussed in more detail in Report III.

The priming effect in dichotic listening may not be limited to the prime-dichotic syllable pairings used in the present experiments, but it may also be possible to see similar effects when using sequences of dichotic syllable, in the sense that one trial has a priming effect on the next trial. Such an experimental design would to a larger extent than the present design be a hybrid between traditional dichotic listening experiments and negative priming experiments. If such a design finds priming effects, it would indicate that priming effects can be present in traditional dichotic listening experiments, regardless of whether the researcher intends to examine priming. Preliminary work has been done on an experiment with this design, see section 6.6.

The current thesis indicates that dichotic listening responses are not merely the result of perceptual processes that are influenced by brain asymmetry, but that higher cognitive functions are involved in determining dichotic listening responses, and that dichotic listening may be an interesting approach to study frontal functions. A similar point has been raised by Bethmann and colleagues (Bethmann, Tempelmann, De Bleser, Scheich, & Brechmann, 2007). Not only is voluntary intention involved in selecting among available inputs, as indicated by previous research, but the context the stimuli appear in (i.e. residual effects of recent events) appears to automatically invoke mechanisms of cognitive control and inhibition.

6.3 Implications for cognitive control models

In the current experiments, response accuracy was used as a measure of cognitive control, while most experiments in the literature measuring cognitive control (such as the go/no-go tasks, the flanker task and the Stroop task, see section 1.3.3), show cognitive control in terms of RT differences. In the current studies cognitive control appears to have been applied as an automatic reaction to complex auditory stimuli, rather than based on explicit task instructions. Additionally, the experiment used stimuli that were clearly perceptible, but ambiguous in nature, as opposed to other cognitive control tasks that rely on stimuli being presented near or below the perceptual threshold, or with special presentation modes (such as visual half-field studies) in order to produce the effect. Compared to the more established experiments used to study cognitive control, the current experiment task may thus have the advantage of being somewhat more ecologically relevant, as the effect is seen on response selection between ambiguous verbal stimuli and independent of task instructions.

Report III showed that within a stimulus condition that is assumed to invoke cognitive control and has behavioural and activation data to support this assumption, the condition can be further subdivided and analysed based on the responses made. The categorisation based on behavioural response selection allowed for improved model fit for both the RT and the activation data. The implication appears to be that experimental tasks that study cognitive control may benefit from classifying trials not only based on stimulus relationships, but also based on the response selections made.

Based on research on positive priming (see section 2.1) and on experiments that show both positive and negative effects of priming for the same task depending on stimulus relationships (see section 2.2), it could be argued that the repetition of a syllable in the current experiments would inevitably cause positive priming, due to the residual effect of previous excitation (see section 4.2.1). From this perspective, the fact that the current experiments showed an overall negative priming effect may be understood as there being factors driving the response toward both positive and negative priming, but that the negative priming effect is of greater magnitude in the current design, and is thus the effect seen on response selection. Such a two-process model cannot be supported or rejected from the currently presented experiments, but future follow-up studies may resolve the issue, for example by experimentally modulating whether the prime syllable is attended or inhibited.

6.4 Implications for models of negative priming

Despite differences between the experimental design used in the current thesis and the design in the typical negative priming experiment, it could be of interest to examine how the current results relate to the different accounts of negative priming. The inhibition view (Tipper, 1985; 2001) states that negative priming is caused by an attentional inhibitory mechanism, while the episodic retrieval view (Neill, Valdes, Terry, & Gorfein, 1992) states that memory of how the stimulus was previously processed influences current processing of the stimulus. The basic behavioural effect in primed dichotic listening experiments reported in the current thesis is compatible with both views of negative priming. The interaction between the priming manipulation and the instruction manipulation seen in Report II supported the inhibition view of negative priming, since an attentional instruction is more readily understood as interacting with an attentional inhibition mechanism than with an episodic retrieval mechanism. The inhibition view of negative priming also appears to be supported by the results in Report III that showed pMFC and right IFG activations, which would be compatible with cognitive control and inhibitory mechanisms, while the episodic retrieval view appears to receive less direct support from the current fMRI results. Report II and III thus appear to lend more support to the inhibition view of negative priming, than to the episodic retrieval view. However, if the episodic retrieval view can, as Tipper (2001) suggested, be reformulated within an inhibition framework, the activations in Report III can to a larger extent be compatible with both views, as the PFC activations can represent either conflict between current stimuli and an inhibition of prime stimulus, or it can represent conflict between current stimuli and an episodic "do not respond" trace.

6.5 Potential clinical implications

The main finding in the current thesis is that the primed dichotic listening task is solved through mechanisms of cognitive control and inhibition. This may have clinical relevance, as failures of these functions are core symptoms in several psychiatric disorders. It would thus be of interest to further develop the task in order to use it to measure inter-individual variation in cognitive control and inhibition. The primed dichotic listening task may have some advantages compared to other tasks that test cognitive control (see sections 4.1.1 and 6.3). One of them is that the attention control appears to occur independently of the participant's intention to direct attention, and the cognitive function can thus be tested relatively independently of task compliance. Further, cognitive control is tested while using relative simple instructions, and the effect is reliable and thus needs a low number of trials to be observed. This allows the primed dichotic listening procedure to be combined with other experiment factors. It may be of particular interest to repeat the design from

Report II on a clinical group and a control group, as it has two measures of cognitive control that may vary independently.

6.6 Future work

The current thesis has shown a new approach to manipulating dichotic listening responses with priming and this has been explained through the concepts of cognitive conflict and inhibition. It was suggested that it is not the exposure to a prime stimulus in itself, but the type and amount of processing performed on the prime stimulus that is important for the subsequent processing of targets. Future work is needed to investigate through which mechanism and under which conditions priming has an effect on dichotic listening performance. As outlined earlier (see section 6.2), one approach to test these aspect of the model would be to use a sequence of dichotic syllable pairs, where one of the syllables in the pair on trial^{n} could prime one of the syllables in the pair on trial^{n+1}. As an example, trial^{n} presents /ga-ba/ and trial^{n+1} presents /ga-da/. The /ga/ on trial^{n} would be considered a prime, as it is repeated in the trial^{n+1} syllable pair, and on trial^{n+1} /ga/ would be the primed syllable while /da/ would be the unprimed syllable. One would test for whether response selection on trial^{n+1} favoured /ga/ (positive priming) or /da/ (negative priming). Such a design may provide a more detailed theoretical model for primed dichotic listening, since it would be possible to make stronger assumptions about what sort of processing has been performed on the prime stimulus. This could be done by comparing the responses made on trial^{n+1} not only with the stimuli presented on trial^{n}, but also with the responses made on trial^{n+1}. Preliminary data indicates that an experiment of this type shows an overall negative priming effect. However, categorising trial^{n+1} responses according to the responses made on trial^{n} reveals that trial^{n+1} responses only show negative priming if the prime syllable was "selected against" on trial^{n}. Transferring this to the example above, there would be a negative priming effect of selecting /da/ on trial^{n+1} only if /ba/ rather than /ga/ was selected on trial^{n}. This preliminary result supports the model presented in the thesis: The negative effect of priming in primed dichotic listening is due to currently attending a recently inhibited stimulus, not merely the repetition of stimuli. An additional experimental design to further explore the effect of cognitive operations performed on the prime stimulus, could be to have a pre-onset cue that signals whether or not the participant should respond to the syllables of trial^{n}. One could then see whether the priming effect of trial^{n} syllable pair on responding to trial^{n+1} syllable pair is contingent on whether a response was required on trial^{n} (indicating that the prime stimulus was attended or inhibited) or no response was required (indicating no attention or inhibition of the prime).

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List of publications

I. Sætrevik, B., & Hugdahl, K. (2007b). Priming inhibits the right ear advantage in dichotic listening. *Neuropsychologia, 45*(2), 282-287.

II. Sætrevik, B., & Hugdahl, K. (2007a). Endogenous and exogenous control of attention in dichotic listening. *Neuropsychology, 21*(3), 285-290.

III. Sætrevik, B., Specht, K., & Hugdahl, K. (submitted to Acta Psychologica after revisions on November 12th, 2007). An fMRI study of priming in dichotic listening shows inhibition of attention.

Doctoral Theses at The Faculty of Psychology, University of Bergen

1980	Allen, H.M., Dr. philos.	Parent-offspring interactions in willow grouse (Lagopus L. Lagopus).
1981	Myhrer, T., Dr. philos.	Behavioral Studies after selective disruption of hippocampal inputs in albino rats.
1982	Svebak, S., Dr. philos.	The significance of motivation for task-induced tonic physiological changes.
1983	Myhre, G., Dr. philos.	The Biopsychology of behavior in captive Willow ptarmigan.
	Eide, R., Dr. philos.	PSYCHOSOCIAL FACTORS AND INDICES OF HEALTH RISKS. The relationship of psychosocial conditions to subjective complaints, arterial blood pressure, serum cholesterol, serum triglycerides and urinary catecholamines in middle aged populations in Western Norway.
	Værnes, R.J., Dr. philos.	Neuropsychological effects of diving.
1984	Kolstad, A., Dr. philos.	Til diskusjonen om sammenhengen mellom sosiale forhold og psykiske strukturer. En epidemiologisk undersøkelse blant barn og unge.
	Løberg, T., Dr. philos.	Neuropsychological assessment in alcohol dependence.
1985	Hellesnes, T., Dr. philos.	Læring og problemløsning. En studie av den perseptuelle analysens betydning for verbal læring.
	Håland, W., Dr. philos.	Psykoterapi: relasjon, utviklingsprosess og effekt.
1986	Hagtvet, K.A., Dr. philos.	The construct of test anxiety: Conceptual and methodological issues.
	Jellestad, F.K., Dr. philos.	Effects of neuron specific amygdala lesions on fear-motivated behavior in rats.
1987	Aarø, L.E., Dr. philos.	Health behaviour and sosioeconomic Status. A survey among the adult population in Norway.
	Underlid, K., Dr. philos.	Arbeidsløyse i psykososialt perspektiv.
	Laberg, J.C., Dr. philos.	Expectancy and classical conditioning in alcoholics' craving.
	Vollmer, F.C., Dr. philos.	Essays on explanation in psychology.
	Ellertsen, B., Dr. philos.	Migraine and tension headache: Psychophysiology, personality and therapy.
1988	Kaufmann, A., Dr. philos.	Antisosial atferd hos ungdom. En studie av psykologiske determinanter.

	Mykletun, R.J., Dr. philos.	Teacher stress: personality, work-load and health.
	Havik, O.E., Dr. philos.	After the myocardial infarction: A medical and psychological study with special emphasis on perceived illness.
1989	Bråten, S., Dr. philos.	Menneskedyaden. En teoretisk tese om sinnets dialogiske natur med informasjons- og utviklingspsykologiske implikasjoner sammenholdt med utvalgte spedbarnsstudier.
	Wold, B., Dr. psychol.	Lifestyles and physical activity. A theoretical and empirical analysis of socialization among children and adolescents.
1990	Flaten, M.A., Dr. psychol.	The role of habituation and learning in reflex modification.
1991	Alsaker, F.D., Dr. philos.	Global negative self-evaluations in early adolescence.
	Kraft, P., Dr. philos.	AIDS prevention in Norway. Empirical studies on diffusion of knowledge, public opinion, and sexual behaviour.
	Endresen, I.M., Dr. philos.	Psychoimmuniological stress markers in working life.
	Faleide, A.O., Dr. philos.	Asthma and allergy in childhood. Psychosocial and psychotherapeutic problems.
1992	Dalen, K., Dr. philos.	Hemispheric asymmetry and the Dual-Task Paradigm: An experimental approach.
	Bø, I.B., Dr. philos.	Ungdoms sosiale økologi. En undersøkelse av 14-16 åringers sosiale nettverk.
	Nivison, M.E., Dr. philos.	The relationship between noise as an experimental and environmental stressor, physiological changes and psychological factors.
	Torgersen, A.M., Dr. philos.	Genetic and environmental influence on temperamental behaviour. A longitudinal study of twins from infancy to adolescence.
1993	Larsen, S., Dr. philos.	Cultural background and problem drinking.
	Nordhus, I.H., Dr. philos.	Family caregiving. A community psychological study with special emphasis on clinical interventions.
	Thuen, F., Dr. psychol.	Accident-related behaviour among children and young adolescents: Prediction and prevention.
	Solheim, R., Dr. philos.	Spesifikke lærevansker. Diskrepanskriteriet anvendt i seleksjonsmetodikk.
	Johnsen, B.H., Dr. psychol.	Brain assymetry and facial emotional expressions: Conditioning experiments.
1994	Tønnessen, F.E., Dr. philos.	The etiology of Dyslexia.
	Kvale, G., Dr. psychol.	Psychological factors in anticipatory nausea and vomiting in cancer chemotherapy.
	Asbjørnsen, A.E., Dr. psychol.	Structural and dynamic factors in dichotic listening: An interactional model.

	Bru, E., Dr. philos.	The role of psychological factors in neck, shoulder and low back pain among female hospitale staff.
	Braathen, E.T., Dr. psychol.	Prediction of exellence and discontinuation in different types of sport: The significance of motivation and EMG.
	Johannessen, B.F., Dr. philos.	Det flytende kjønnet. Om lederskap, politikk og identitet.
1995	Sam, D.L., Dr. psychol.	Acculturation of young immigrants in Norway: A psychological and socio-cultural adaptation.
	Bjaalid, I.-K., Dr. philos	Component processes in word recognition.
	Martinsen, Ø., Dr. philos.	Cognitive style and insight.
	Nordby, H., Dr. philos.	Processing of auditory deviant events: Mismatch negativity of event-related brain potentials.
	Raaheim, A., Dr. philos.	Health perception and health behaviour, theoretical considerations, empirical studies, and practical implications.
	Seltzer, W.J., Dr.philos.	Studies of Psychocultural Approach to Families in Therapy.
	Brun, W., Dr.philos.	Subjective conceptions of uncertainty and risk.
	Aas, H.N., Dr. psychol.	Alcohol expectancies and socialization: Adolescents learning to drink.
	Bjørkly, S., Dr. psychol.	Diagnosis and prediction of intra-institutional aggressive behaviour in psychotic patients
1996	Anderssen, N., Dr. psychol.	Physical activity of young people in a health perspective: Stability, change and social influences.
	Sandal, Gro Mjeldheim, Dr. psychol.	Coping in extreme environments: The role of personality.
	Strumse, Einar, Dr. philos.	The psychology of aesthetics: explaining visual preferences for agrarian landscapes in Western Norway.
	Hestad, Knut, Dr. philos.	Neuropsychological deficits in HIV-1 infection.
	Lugoe, L.Wycliffe, Dr. philos.	Prediction of Tanzanian students' HIV risk and preventive behaviours
	Sandvik, B. Gunnhild, Dr. philos.	Fra distriktsjordmor til institusjonsjordmor. Fremveksten av en profesjon og en profesjonsutdanning
	Lie, Gro Therese, Dr. psychol.	The disease that dares not speak its name: Studies on factors of importance for coping with HIV/AIDS in Northern Tanzania
	Øygard, Lisbet, Dr. philos.	Health behaviors among young adults. A psychological and sociological approach
	Stormark, Kjell Morten, Dr. psychol.	Emotional modulation of selective attention: Experimental and clinical evidence.
	Einarsen, Ståle, Dr. psychol.	Bullying and harassment at work: epidemiological and psychosocial aspects.

1997	Knivsberg, Ann-Mari, Dr. philos.	Behavioural abnormalities and childhood psychopathology: Urinary peptide patterns as a potential tool in diagnosis and remediation.
	Eide, Arne H., Dr. philos.	Adolescent drug use in Zimbabwe. Cultural orientation in a global-local perspective and use of psychoactive substances among secondary school students.
	Sørensen, Marit, Dr. philos.	The psychology of initiating and maintaining exercise and diet behaviour.
	Skjæveland, Oddvar, Dr. psychol.	Relationships between spatial-physical neighborhood attributes and social relations among neighbors.
	Zewdie, Teka, Dr. philos.	Mother-child relational patterns in Ethiopia. Issues of developmental theories and intervention programs.
	Wilhelmsen, Britt Unni, Dr. philos.	Development and evaluation of two educational programmes designed to prevent alcohol use among adolescents.
	Manger, Terje, Dr. philos.	Gender differences in mathematical achievement among Norwegian elementary school students.
1998		
V	Lindstrøm, Torill Christine, Dr. philos.	«Good Grief»: Adapting to Bereavement.
	Skogstad, Anders, Dr. philos.	Effects of leadership behaviour on job satisfaction, health and efficiency.
	Haldorsen, Ellen M. Håland, Dr. psychol.	Return to work in low back pain patients.
	Besemer, Susan P., Dr. philos.	Creative Product Analysis: The Search for a Valid Model for Understanding Creativity in Products.
H	Winje, Dagfinn, Dr. psychol.	Psychological adjustment after severe trauma. A longitudinal study of adults' and children's posttraumatic reactions and coping after the bus accident in Måbødalen, Norway 1988.
	Vosburg, Suzanne K., Dr. philos.	The effects of mood on creative problem solving.
	Eriksen, Hege R., Dr. philos.	Stress and coping: Does it really matter for subjective health complaints?
	Jakobsen, Reidar, Dr. psychol.	Empiriske studier av kunnskap og holdninger om hiv/aids og den normative seksuelle utvikling i ungdomsårene.
1999		
V	Mikkelsen, Aslaug, Dr. philos.	Effects of learning opportunities and learning climate on occupational health.
	Samdal, Oddrun, Dr. philos.	The school environment as a risk or resource for students' health-related behaviours and subjective well-being.
	Friestad, Christine, Dr. philos.	Social psychological approaches to smoking.
	Ekeland, Tor-Johan, Dr. philos.	Meining som medisin. Ein analyse av placebofenomenet og implikasjoner for terapi og terapeutiske teoriar.
H	Saban, Sara, Dr. psychol.	Brain Asymmetry and Attention: Classical Conditioning Experiments.

	Carlsten, Carl Thomas, Dr. philos.	God lesing – God læring. En aksjonsrettet studie av undervisning i fagtekstlesing.
	Dundas, Ingrid, Dr. psychol.	Functional and dysfunctional closeness. Family interaction and children's adjustment.
	Engen, Liv, Dr. philos.	Kartlegging av leseferdighet på småskoletrinnet og vurdering av faktorer som kan være av betydning for optimal leseutvikling.
2000		
V	Hovland, Ole Johan, Dr. philos.	Transforming a self-preserving "alarm" reaction into a self-defeating emotional response: Toward an integrative approach to anxiety as a human phenomenon.
	Lillejord, Sølvi, Dr. philos.	Handlingsrasjonalitet og spesialundervisning. En analyse av aktørperspektiver.
	Sandell, Ove, Dr. philos.	Den varme kunnskapen.
	Oftedal, Marit Petersen, Dr. philos.	Diagnostisering av ordavkodingsvansker: En prosessanalytisk tilnærmingsmåte.
H	Sandbak, Tone, Dr. psychol.	Alcohol consumption and preference in the rat: The significance of individual differences and relationships to stress pathology
	Eid, Jarle, Dr. psychol.	Early predictors of PTSD symptom reporting; The significance of contextual and individual factors.
2001		
V	Skinstad, Anne Helene, Dr. philos.	Substance dependence and borderline personality disorders.
	Binder, Per-Einar, Dr. psychol.	Individet og den meningsbærende andre. En teoretisk undersøkelse av de mellommenneskelige forutsetningene for psykisk liv og utvikling med utgangspunkt i Donald Winnicotts teori.
	Roald, Ingvild K., Dr. philos.	Building of concepts. A study of Physics concepts of Norwegian deaf students.
H	Fekadu, Zelalem W., Dr. philos.	Pridicting contraceptive use and intention among a sample of adolescent girls. An application of the theory of planned behaviour in Ethiopian context.
	Melesse, Fantu, Dr. philos.	The more intelligent and sensitive child (MISC) mediational intervention in an Ethiopian context: An evaluation study.
	Råheim, Målfrid, Dr. philos.	Kvinners kroppserfaring og livssammenheng. En fenomenologisk – hermeneutisk studie av friske kvinner og kvinner med kroniske muskelsmerter.
	Engelsen, Birthe Kari, Dr. psychol.	Measurement of the eating problem construct.
	Lau, Bjørn, Dr. philos.	Weight and eating concerns in adolescence.
2002		
V	Ihlebæk, Camilla, Dr. philos.	Epidemiological studies of subjective health complaints.
	Rosén, Gunnar O. R., Dr. philos.	The phantom limb experience. Models for understanding and treatment of pain with hypnosis.

	Høines, Marit Johnsen, Dr. philos.	Fleksible språkrom. Matematikklæring som tekstutvikling.
	Anthun, Roald Andor, Dr. philos.	School psychology service quality. Consumer appraisal, quality dimensions, and collaborative improvement potential
	Pallesen, Ståle, Dr. psychol.	Insomnia in the elderly. Epidemiology, psychological characteristics and treatment.
	Midthassel, Unni Vere, Dr. philos.	Teacher involvement in school development activity. A study of teachers in Norwegian compulsory schools
	Kallestad, Jan Helge, Dr. philos.	Teachers, schools and implementation of the Olweus Bullying Prevention Program.
H	Ofte, Sonja Helgesen, Dr. psychol.	Right-left discrimination in adults and children.
	Netland, Marit, Dr. psychol.	Exposure to political violence. The need to estimate our estimations.
	Diseth, Åge, Dr. psychol.	Approaches to learning: Validity and prediction of academic performance.
	Bjuland, Raymond, Dr. philos.	Problem solving in geometry. Reasoning processes of student teachers working in small groups: A dialogical approach.
2003 V	Arefjord, Kjersti, Dr. psychol.	After the myocardial infarction – the wives' view. Short- and long-term adjustment in wives of myocardial infarction patients.
	Ingjaldsson, Jón Þorvaldur, Dr. psychol.	Unconscious Processes and Vagal Activity in Alcohol Dependency.
	Holden, Børge, Dr. philos.	Følger av atferdsanalytiske forklaringer for atferdsanalysens tilnærming til utforming av behandling.
	Holsen, Ingrid, Dr. philos.	Depressed mood from adolescence to 'emerging adulthood'. Course and longitudinal influences of body image and parent-adolescent relationship.
	Hammar, Åsa Karin, Dr. psychol.	Major depression and cognitive dysfunction- An experimental study of the cognitive effort hypothesis.
	Sprugevica, Ieva, Dr. philos.	The impact of enabling skills on early reading acquisition.
	Gabrielsen, Egil, Dr. philos.	LESE FOR LIVET. Lesekompetansen i den norske voksenbefolkningen sett i lys av visjonen om en enhetsskole.
H	Hansen, Anita Lill, Dr. psychol.	The influence of heart rate variability in the regulation of attentional and memory processes.
	Dyregrov, Kari, Dr. philos.	The loss of child by suicide, SIDS, and accidents: Consequences, needs and provisions of help.
2004 V	Torsheim, Torbjørn, Dr. psychol.	Student role strain and subjective health complaints: Individual, contextual, and longitudinal perspectives.
	Haugland, Bente Storm Mowatt Dr. psychol.	Parental alcohol abuse. Family functioning and child adjustment.

	Milde, Anne Marita, Dr. psychol.	Ulcerative colitis and the role of stress. Animal studies of psychobiological factors in relationship to experimentally induced colitis.
	Stornes, Tor, Dr. philos.	Socio-moral behaviour in sport. An investigation of perceptions of sportspersonship in handball related to important factors of socio-moral influence.
	Mæhle, Magne, Dr. philos.	Re-inventing the child in family therapy: An investigation of the relevance and applicability of theory and research in child development for family therapy involving children.
	Kobbeltvedt, Therese, Dr. psychol.	Risk and feelings: A field approach.
H	Thomsen, Tormod, Dr. psychol.	Localization of attention in the brain.
	Løberg, Else-Marie, Dr. psychol.	Functional laterality and attention modulation in schizophrenia: Effects of clinical variables.
	Kyrkjebø, Jane Mikkelsen, Dr. philos.	Learning to improve: Integrating continuous quality improvement learning into nursing education.
	Laumann, Karin, Dr. psychol.	Restorative and stress-reducing effects of natural environments: Experiencal, behavioural and cardiovascular indices.
	Holgersen, Helge, PhD	Mellom oss - Essay i relasjonell psykoanalyse.
2005		
V	Hetland, Hilde, Dr. psychol.	Leading to the extraordinary? Antecedents and outcomes of transformational leadership.
	Iversen, Anette Christine, Dr. philos.	Social differences in health behaviour: the motivational role of perceived control and coping.
H	Mathisen, Gro Ellen, PhD	Climates for creativity and innovation: Definitions, measurement, predictors and consequences.
	Sævi, Tone, Dr. philos.	Seeing disability pedagogically – The lived experience of disability in the pedagogical encounter.
	Wiium, Nora, PhD	Intrapersonal factors, family and school norms: combined and interactive influence on adolescent smoking behaviour.
	Kanagaratnam, Pushpa, PhD	Subjective and objective correlates of Posttraumatic Stress in immigrants/refugees exposed to political violence.
	Larsen, Torill M. B. , PhD	Evaluating principals` and teachers` implementation of Second Step. A case study of four Norwegian primary schools.
	Bancila, Delia, PhD	Psychosocial stress and distress among Romanian adolescents and adults.
2006		
V	Hillestad, Torgeir Martin, Dr. philos.	Normalitet og avvik. Forutsetninger for et objektivt psykopatologisk avviksbegrep. En psykologisk, sosial, erkjennelsesteoretisk og teorihistorisk framstilling.
	Nordanger, Dag Øystein, Dr. psychol.	Psychosocial discourses and responses to political violence in post-war Tigray, Ethiopia.

	Rimol, Lars Morten, PhD	Behavioral and fMRI studies of auditory laterality and speech sound processing.
	Krumsvik, Rune Johan, Dr. philos.	ICT in the school. ICT-initiated school development in lower secondary school.
	Norman, Elisabeth, Dr. psychol.	Gut feelings and unconscious thought: An exploration of fringe consiousness in implicit cognition.
	Israel, K Pravin, Dr. psychol.	Parent involvement in the mental health care of children and adolescents. Emperical studies from clinical care setting.
	Glasø, Lars, PhD	Affects and emotional regulation in leader-subordinate relationships.
	Knutsen, Ketil, Dr. philos.	HISTORIER UNGDOM LEVER – En studie av hvordan ungdommer bruker historie for å gjøre livet meningsfullt.
	Matthiesen, Stig Berge, PhD	Bullying at work. Antecedents and outcomes.
H	Gramstad, Arne, PhD	Neuropsychological assessment of cognitive and emotional functioning in patients with epilepsy.
	Bendixen, Mons, PhD	Antisocial behaviour in early adolescence: Methodological and substantive issues.
	Mrumbi, Khalifa Maulid, PhD	Parental illness and loss to HIV/AIDS as experienced by AIDS orphans aged between 12-17 years from Temeke District, Dar es Salaam, Tanzania: A study of the children's psychosocial health and coping responses.
	Hetland, Jørn, Dr. psychol.	The nature of subjective health complaints in adolescence: Dimensionality, stability, and psychosocial predictors
	Kakoko, Deodatus Conatus Vitalis, PhD	Voluntary HIV counselling and testing service uptake among primary school teachers in Mwanza, Tanzania: assessment of socio-demographic, psychosocial and socio-cognitive aspects
	Mykletun, Arnstein, Dr. psychol.	Mortality and work-related disability as long-term consequences of anxiety and depression: Historical cohort designs based on the HUNT-2 study
	Sivertsen, Børge, PhD	Insomnia in older adults. Consequences, assessment and treatment.
2007		
V	Singhammer, John, Dr. philos.	Social conditions from before birth to early adulthood – the influence on health and health behaviour
	Janvin, Carmen Ani Cristea, PhD	Cognitive impairment in patients with Parkinson's disease: profiles and implications for prognosis
	Braarud, Hanne Cecilie, Dr.psychol.	Infant regulation of distress: A longitudinal study of transactions between mothers and infants
	Tveito, Torill Helene, PhD	Sick Leave and Subjective Health Complaints
	Magnussen, Liv Heide, PhD	Returning disability pensioners with back pain to work

	Thuen, Elin Marie, Dr.philos.	Learning environment, students' coping styles and emotional and behavioural problems. A study of Norwegian secondary school students.
	Solberg, Ole Asbjørn, PhD	Peacekeeping warriors – A longitudinal study of Norwegian peacekeepers in Kosovo
H	Søreide, Gunn Elisabeth, Dr.philos.	Narrative construction of teacher identity
	Svensen, Erling, PhD	WORK & HEALTH. Cognitive Activation Theory of Stress applied in an organisational setting.
	Øverland, Simon Nygaard, PhD	Mental health and impairment in disability benefits. Studies applying linkages between health surveys and administrative registries.
	Eichele, Tom, PhD	Electrophysiological and Hemodynamic Correlates of Expectancy in Target Processing
	Børhaug, Kjetil, Dr.philos.	Oppseding til demokrati. Ein studie av politisk oppseding i norsk skule.
	Eikeland, Thorleif, Dr.philos.	Om å vokse opp på barnehjem og på sykehus. En undersøkelse av barnehjemsbarns opplevelser på barnehjem sammenholdt med sanatoriebarns beskrivelse av langvarige sykehusopphold – og et forsøk på forklaring.
	Wadel, Carl Cato, Dr.philos.	Medarbeidersamhandling og medarbeiderledelse i en lagbasert organisasjon
	Vinje, Hege Forbech, PhD	Thriving despite adversity: Job engagement and self-care among community nurses
	Noort, Maurits van den, PhD	Working memory capacity and foreign language acquisition
2008		
V	Breivik, Kyrre, Dr.psychol.	The Adjustment of Children and Adolescents in Different Post-Divorce Family Structures. A Norwegian Study of Risks and Mechanisms.
	Johnsen, Grethe E., PhD	Memory impairment in patients with posttraumatic stress disorder